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A MULTI-ATTRIBUTE DECISION ANALYSIS APPROACH TO THE DEVELOPMENT OF A COMPUTERIZED AID TO MISSION PLANNING (MADCAMP)

THESIS

AFIT/GST/OS/81M-11

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This study investigates the problem of real time low-level mission planning against highly transient targets within the Battlefield Air Interdiction (BAI) environment. The dual objective was to test the feasibility of a computerized mission planning aid and reducing computer memory requirements to a level that would allow implementation of the mission planning aid on a modern mini-computer system. The model is based on concept of using Multi-Attribute Decision Analysis (MADA) to capture

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the decision making process of experienced mission planners and Selective Terrain Mapping (STM) to reduce the computer data storage requirements. The model uses a dynamic programming algorithm to produce an "optimal" flight path through a given environment. Optimality is based entirely on the ability to capture the mission planners decision making process. From the results of this study, it was concluded that the approach is feasible, the model will produce acceptable flight paths, the mission planners' decision making process can be captured using MADA, and STM will adequately reduce the computer storage requirements.

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

Robert H. Whitney
Capt USAF

Jack L. Wilson
Maj USAF

March 1981

Approved for public release; distribution unlimited.

Preface

This study is a result of the increasing emphasis being placed on Battlefield Air Interdiction (BAI) and the need for a computerized mission planning aid capable of producing acceptable low-level flight plans in a minimum of time, using near real time intelligence data. The targets within the BAI arena are, for the most part, highly transient and to be successfully attacked demands a minimum aircrew preparation time. The sooner the aircrews can reach the target area, the higher the probability of finding the assigned target. Our interest in this particular problem stems from several years of experience in and association with the tactical fighter mission.

We would like to thank everyone that has assisted us with or participated in this study. In particular we thank our advisor Major Dan Fox, our readers Ltc Jim Havey and Prof Dan Reynolds, the tactical aircrew members of the faculty and Class GST 81-M for completing the questionnaire and assisting in establishing the scoring function, and the 388TFW Hill AFB, Ut for preparing the five sets of source routes used in the analysis phase of the study. We extend a special thanks and appreciation to our families for the support they have given and the sacrifices they have made in helping us to complete this study.

Maj Jack Wilson
Capt Bob Whitney

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Abstract

This study investigates the problem of real time low-level mission planning against highly transient targets within the Battlefield Air Interdiction (BAI) environment. The dual objective was to test the feasibility of a computerized mission planning aid and reducing computer memory requirements to a level that would allow implementation of the mission planning aid on a modern mini-computer system.

The model is based on concept of using Multi-Attribute Decision Analysis (MADA) to capture the decision making process of experienced mission planners and Selective Terrain Mapping (STM) to reduce the computer data storage requirements. The model uses a dynamic programming algorithm to produce an "optimal" flight path through a given environment. Optimality is based entirely on the ability to capture the mission planners decision making process.

From the results of this study, it was concluded that the approach is feasible, the model will produce acceptable flight paths, the mission planners' decision making process can be captured using MADA, and STM will adequately reduce the computer storage requirements.

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TO THE DEVELOPMENT OF A
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1 Problem Statement

1.1 Introduction

The character of air interdiction has changed a great deal in the past and can be expected to do so continuously in the future. Increased emphasis on electronic equipment to suppress enemy air-defenses, new weapons, and more sophisticated delivery systems are a few of the areas in which major changes have been seen in recent years. Hardware is, however, only part of the overall picture when examining the effectiveness of air interdiction. The role of mission planning, and specifically the mission planner, is equally important. Sophisticated weapons and tactics are of little importance if they are not employed effectively.

The purpose of interdiction is to destroy, neutralize, confuse and delay enemy ground forces. This is accomplished by attacking the enemy's logistical system in order to reduce the movement of needed supplies and reinforcements to the battlefield. Primary targets include the enemy's transportation systems, communications facilities, and supply sources.

Although air interdiction has been a recognized military tool since World War II, it has been the subject of considerable debate in recent years. The primary issue is whether air interdiction has a place in the modern battlefield environment. The effect that disruption of logistical support has upon the enemy's ability to wage war cannot generally be observed immediately. There is a finite time before losses will be felt on the front lines thus affecting directly the outcome of a battle. Some argue that in a highly mobile, concentrated thrust, which could be expected in Europe, the effect would be felt too late to prevent a major breakthrough. For this reason, the role of air interdiction is questioned.

To counter this argument, it is felt that air interdiction activity will be required to move closer to the battlefield. This drives the air interdiction effort to supporting specific battlefields rather than attacking the enemy's logistical system in general. Major General Leslie W. Bray, Jr., recognized the need for this shift of attention in the early 1970's. He coined the term "tactical counterforce" to describe the concept. The purpose of tactical counterforce is; ". . . to destroy, damage and disrupt enemy ground forces not engaged with friendly land forces so the enemy can no longer use these forces to systain the momentum of his offensive (or depth of defense)" (1). In more recent years the term Battlefield Air Interdiction (BAI) has been adopted to identify this mission concept. BAI is defined as that

category of air interdiction flown in the battlefield area between the fire support coordination line and the reconnaissance and interdiction planning line. This area will extend from approximately 95-125 km beyond the forward line of the friendly troops (12). Although there has been considerable debate over its relative importance when compared to close air support and air interdiction, BAI has undisputably become a recognized mission for the employment of tactical airpower. The characteristics of this mission will have considerable impact upon the mission planning process.

The battlefield might be pictured as the mouth of a funnel opening toward the heartland of the enemy. Resources are drawn from a wide area and gradually funneled to a small front where the battle is actually fought. The funneling action is accomplished to increase the density of firepower in order to defeat an opposing force. As might be expected, the types of targets and the air-defense threat will change as attention is moved from the rear areas toward the mouth of the funnel (Fig. 1-1).

Typical targets found in areas well back of the battlefield are manufacturing facilities, large storage complexes, and railway centers. These types of target complexes are similar in that they are relatively large and of a permanent nature. As concern moves closer to the battlefield, target complexes become smaller and tend to be more transient. These characteristics are driven by consideration for survivability and responsiveness to front line needs.

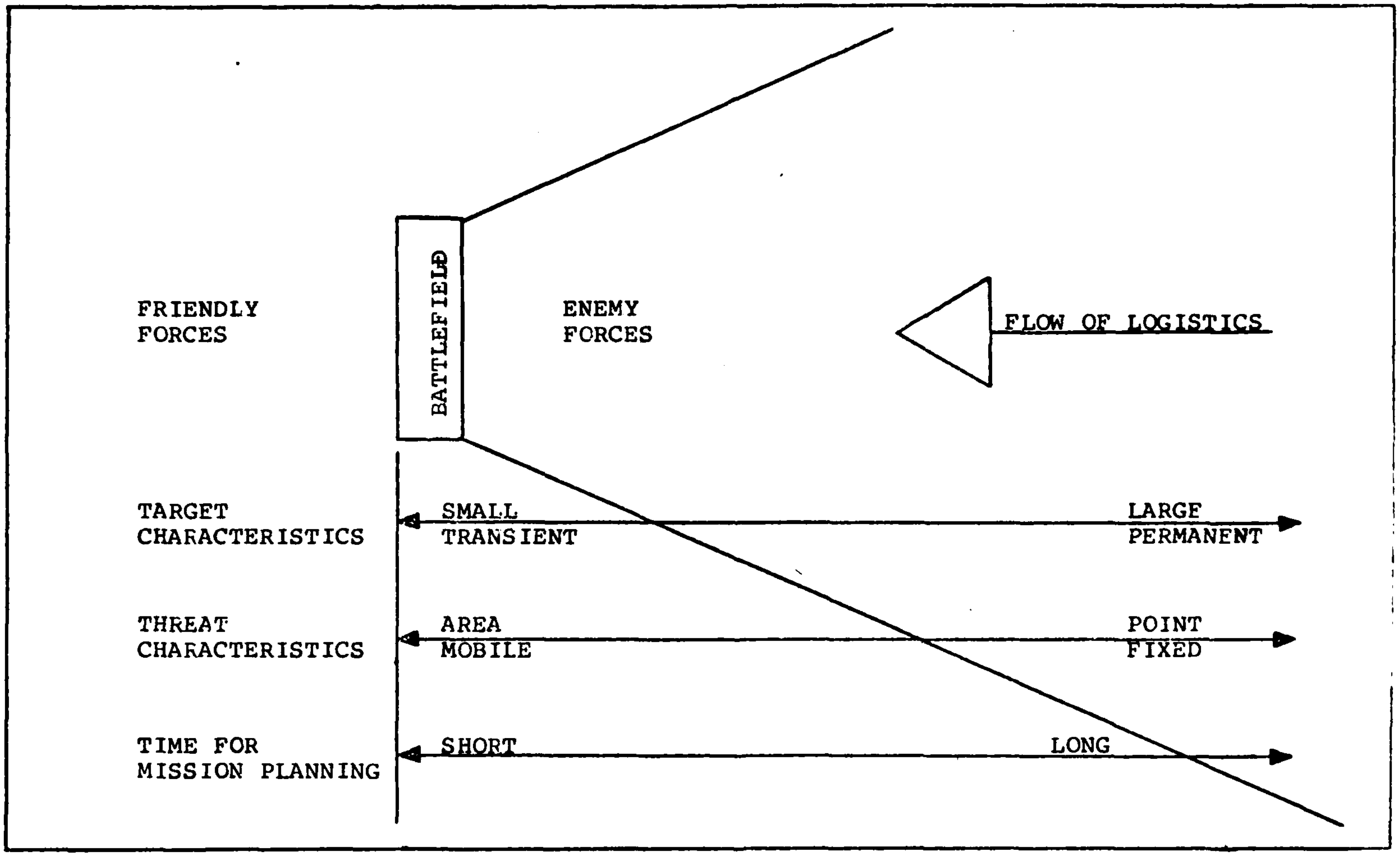


Fig. 1-1 Changing Interdiction Environment

The air-defense threat can also be expected to vary. In rear areas, air-defenses would be of a point rather than area type with emphasis placed upon permanent facilities. Considerable reliance upon air-defense aircraft in this region would also be likely. As the forward edge of the battlefield (FEBA) is approached, a transition from permanent, point defenses to mobile, area defenses will occur. There are two primary reasons for this. First, the area to be covered will be quite small, and second, the density of target complexes will be high. A large number of air-defense systems can be expected in this region because of the concentration of forces.

As emphasis is placed on attacking targets closer and closer to the battlefield, increased demands upon the interdiction mission planner will result. Target mobility effectively reduces the total time in which to plan a mission. There is a finite length of time required from detection of a potential target complex to the creation of a mission plan. Although attempts have been made to reduce this time by development of new reconnaissance and communications equipment and procedures, the fact remains that considerable time will be expended before the mission planner can begin work. This results in a requirement for increased responsiveness in the mission planning process. In addition, increased air-defense threat density will make targets more difficult to attack successfully. It is apparent that a shift of emphasis

toward the battlefield air interdiction environment will require that the mission planner be able to effectively plan in a reduced length of time. Accomplishing this task may be a formidable challenge but it is one which is becoming increasingly important.

1.2 Problem Statement

The problem is to increase the responsiveness of the mission planning process by reducing the length of time required to plan a mission once a potential target or target area has been identified.

1.3 Solution Criteria

To reduce the time required, the mission planner will require an automated mission planning aid. Such an aid must possess a number of important characteristics, such as:

1. The system must provide tactically acceptable mission plans in a relatively short period of time, perhaps a few minutes.
2. The system must be portable enough to be deployable with units in a war time environment.
3. The system must be reliable so as to require a minimum of maintenance support.
4. The system must be capable of operating with any level of threat location intelligence.
5. The system must be capable of providing sufficient information to the pilot to allow accomplishment of the mission without extensive briefing time. (Possibly with aircrews in either ground or airborne alert status.)

In addition, such a system must consider as a minimum low-level, terrain following, penetration tactics and terrain masking from suspected threat locations.

2 Proposed Solution

2.1 Background

Following identification of a potential target, a number of decisions are made prior to initiating the detailed mission planning task. Among these are:

1. Is the target worth attacking?
2. What weapon system should be employed?
3. Which unit should perform the mission?

The result of this process, provided the target is to be attacked, is a tasking order (FRAG) which places responsibility for detailed planning with the selected unit. The unit, then, determines an appropriate weapon configuration for the aircraft, schedules the aircraft and tasks a specific aircrew. Ultimately, the aircrew is responsible for accomplishing the detailed mission plan which consists primarily of selecting an acceptable routing to a point which will allow delivery of the weapon on the target.

The nature of the BAI environment does not provide sufficient time for tailoring the aircraft's configuration for a specific mission. The aircraft will have to be on an alert status (either ground or air) with a predetermined weapon configuration if response times are to be realistic. Therefore, the detailed flight planning done by the aircrew will be the most time consuming step at the unit level. This, then, should be a lucrative area in which to focus attention in order to increase overall responsiveness.

One method to reduce the length of time required to produce an acceptable flight plan would be to accomplish this step in advance. A number of canned flight plans could be produced and the aircrews simply select the one which fits their mission requirements best. Although appealing at first glance, the approach has some serious flaws. A large number of these canned routes would have to exist to cover the range of potential target locations and to ensure a sufficient degree of flight path randomness. Without flight path randomness, the enemy would soon establish defensive locations which would make these routes useless. As the number of routes becomes large, the time required to screen them and to choose the best alternative would increase. Ultimately, this could become a more lengthy process than producing a separate flight plan for each mission.

Regardless of the number of canned routes produced, mission effectiveness would be reduced due to a loss of planning flexibility. The ability to use current intelligence information and real time operational restrictions during the flight planning process would be seriously limited. For these reasons, a mission planning aid which uses current mission related data and is capable of producing flight paths tailored to a specific mission is desirable.

A number of computer models have been developed which have the capability to aid the mission planner in the flight planning task (9). A few are:

1. Experimental Penetration Analysis Support System (EPASS)

2. TACTIQUE mission planning system

3. Theatre Mission Planning System (TMPS)

4. Threat Model Penetration Simulation Analysis (TMPSA)

These modeling efforts can be divided into two basic types: flight path analyzers and flight path generators. The basic difference between the two approaches is the method used for obtaining alternative flight paths. The first approach requires that alternative flight paths be generated external to the model and provided as input data while the second generates alternatives internally. Regardless of how the alternative flight paths are produced, the major role of the computer model is to score them so that the best can be chosen. The criteria used to perform the scoring process is, therefore, critical to the acceptability of the output.

Models developed for this purpose generally use probability of survival in some form as the scoring criteria. To accomplish the scoring, they attempt to simulate, with varying degrees of sophistication, the interaction between the potential air-defense threats and the aircraft. Each flight path score consists of a series of single encounters between the aircraft and air-defenses with the value assigned being a function of the particular encounter conditions. This approach to the scoring problem has some drawbacks which make it unsatisfactory in the BAI environment.

The number of factors which affect the probability of survival for an aircraft in an encounter with an air-defense system is very large. Some of these factors are easily

measurable from the encounter geometry, e.g., exposed radar cross-section, while others are more subjective, e.g., ease of defeating a particular missile. Because of this, it is necessary to store a large amount of information concerning encounter along a path. The bookkeeping requirements result in a demand for computer storage capacity which increases as as the number of factors considered and the number of threats increases. The inclusion of terrain masking, vitally important in the BAI environment, places an additional demand on computer capacity. Therefore, if the scoring of alternative flight paths is to be based on a detailed analysis of the encounter conditions, computer storage capacity is potentially a major problem.

Basing the score on encounter conditions necessitates a high degree of certainty concerning enemy air-defense locations. This may well be the case when dealing with penetrations deep into the enemies heartlands where the threats are characteristically more permanent. In the BAI environment, this will certainly not be the case. Air-defense threats in this region can be expected to be highly mobile which makes knowledge of their location extremely uncertain. At any given time the location of only a small percentage of the total threat array will be known. Therefore, a system which relies heavily upon knowledge of air-defense locations has questionable usefulness in this environment. For these reasons, a scoring function which does not require excessive computer storage and is not dependent upon a high degree of air-defense location certainty is needed.

2.2 The Multi-Attribute Approach

The authors feel that an experienced flight planner familiar with low level penetration tactics can, with sufficient time, produce an operationally acceptable flight plan in the BAI environment. Therefore, a scoring function which captures the decision process of experienced flight planners should produce flight plans equally acceptable. Such a function could be based upon a subjective decision process rather than a detailed analysis of encounter conditions. It would be useful, then, to examine the process used by flight planners in producing an acceptable routing.

The flight planner is presented a large amount of information which must be internalized before the planning task can be completed. The type and depth of this information varies depending upon the specific circumstances of the mission. A mission to attack a permanent target complex with established air-defenses will provide the planner with a different type and depth of information than one involving a transitory target close to the FEBA and defended by highly mobile air-defense systems. Regardless of the specific circumstances, the planner can be expected to have access to at least some information concerning:

1. The type and location of potential air-defense systems
2. The nature of the terrain enroute to the target
3. The extent and location of major cultural features enroute to the target
4. Characteristics of the type aircraft to be used

5. Weapons delivery parameters

6. Special military constraints to the mission

It is the task of the mission planner to use all available information to construct a flight path which will provide the highest probability of mission success. To do this, the mission planner must weigh the available information according to some preference structure, make trade-offs, and decide between the alternative flight paths. The objective is to select the alternative which best satisfies the planner's criteria which have been developed primarily from experience. In general, the more alternatives considered by the planner the more acceptable the final product. If the planner's preference structure could be captured in a mathematical function, the process could be automated allowing the evaluation of a large number of alternatives in a short period of time.

Multi-attribute decision theory provides the framework for mathematically expressing preference structures in order to perform value trade-offs between competing alternatives. Because these techniques consider multiple factors in the decision process, they should be more capable of handling uncertainties associated with threat location than the other methods discussed. In addition, the computer requirements should be considerably less because a detailed simulation of encounter conditions would not be necessary. For these

reasons, a multi-attribute decision approach to a computer aided mission planning (MADCAMP) system may provide an operationally feasible method of shortening flight planning time requirements and improve the overall responsiveness of the BAI mission planning process.

3 The Study

3.1 Objective

The objective of this study is to investigate the feasibility of using a multi-attribute decision approach to generate operationally acceptable flight paths in a battlefield air interdiction environment.

3.2 Methodology

The study was approached in four phases. These were:

(1) Prototype System Formulation

(2) Scenario Development

(3) Experimentation

(4) Analysis

Each of these phases is discussed below. The prototype MADCAMP system was developed only as far as necessary to allow construction of test flight paths. No attempt was made to produce a fully operational system.

3.2.1 Prototype System Formulation. In this phase, the goal was to produce a prototype computer mission planning system utilizing a multi-attribute decision analysis technique (MADCAMP). The MADCAMP system developed must provide a means for accomplishing the comparison of a large number of alternatives in a short period of time using the preference structure determined by the planner.

3.2.1.1 The Flight Path Generation Scheme. There are several methods which might be used to generate alternative flight paths. It would be possible to have the mission planner provide the alternative paths one at a time to a system which would score them by comparing each to the mission planner's preference structure. The routing that best satisfied the criteria would then be chosen as the best of the alternatives.

Such a scheme is the basis of many mission planning aids developed to date. Unfortunately, this approach has some serious shortcomings. Routes may exist which would better meet the preference structure of the mission planner. This will always be the case when only a limited set of alternatives is considered. Since the routes are devised by a mission planner and the computer system is used only to analyze and score them, the number of alternatives is limited by the time available. In addition, the quality of the result will be dependent upon the particular mission planner's ability to select routes which are reasonably close to the best route obtainable.

A second approach would be to consider all possible routes which might be taken to the target complex within weapon system constraints. Obviously, it would not be possible for a human mission planner to generate the alternatives in this situation. Therefore, the alternatives would have to be produced by the system. Once generated, each alternative would be scored using the preference structure

determined by the mission planner and the alternative scoring highest picked as the optimal path. This approach would eliminate the problem areas cited previously. However, with even a modern, high speed computer, evaluating all possible routes between two points would be impossible. Therefore, a compromise between the two approaches is suggested.

Such a compromise scheme must provide a means for systematically investigating a large number of alternatives within a relatively short period of time. The method selected for implementation required the constructing of a grid over the feasible flight region. The grid makes it possible to generate all flight paths which connect the grid intersections; a finite number. The number of alternative flight paths obtained is directly proportional to the number of grid intersections. As the size of the grid is decreased, the number of intersections is increased and the higher the probability of including the best possible route in the set. Since the time and the amount of computer storage required are also directly proportional to the number of intersections, the size of the grid was an important consideration.

For the following reasons, the grid size selected for this model was one nautical mile square. A pilot cannot be expected to make continuous turns throughout the mission. Due to workload considerations on the aircrew and storage limitations on inertial navigation systems, the mission planner must pick a relatively small number of turnpoints. The result is an approximation of the best path made up of a number of straight line flight segments. For operational

reasons, flight segments are generally chosen which are greater than some minimum time interval, perhaps one minute, and less than some maximum time interval, perhaps three minutes. The minimum interval is chosen for system and aircrew considerations while the maximum is a survivability consideration. When selecting the grid size, it was felt that a minimum of four to five decision points would provide adequate data to allow determination of a flight segment. Since the aircraft used for BAI have speeds at low altitude in the 400 to 500 knot range, a one nautical mile grid would provide a minimum of 7 to 8 decision points per flight segment.

Another consideration in selecting the grid size was the storing of terrain data. If terrain elevations are to be used to determine terrain masking from air-defense systems (preventing detection by using existing terrain features to break line of sight), the elevation of the terrain at points within the feasible flight region must be available to the system. For ease of implementation, it was determined that terrain data would be obtained using and stored using the same grid structure developed for generating the alternative flight paths. Therefore, the size of the grid determines the maximum terrain resolution obtainable. Again, the amount of computer storage required is directly proportional to the number of data points desired. The higher the terrain resolution, low grid dimensions, the more accurately terrain masking can be predicted.

Looking at the characteristics of the BAI environment, the following factors suggest that a one nautical mile grid would provide adequate resolution for predicting terrain masking:

(1) The aircraft will not be at a constant altitude above ground level (AGL) throughout the mission. Although some nominal altitude, perhaps 200 feet, would be desired; terrain, pilot skill and weather would cause fluctuations of several hundred feet from this datum. Therefore, there is considerable uncertainty as to actual aircraft altitude which reduces the obtainable accuracy in predicting terrain masking.

(2) It can be expected that considerable uncertainty will exist in the determination of enemy air-defense locations. Since the enemy air-defenses in the BAI environment will be highly mobile, location uncertainty will be at a maximum. This fact again lowers the accuracy obtainable in predicting terrain masking.

(3) The aircrews will not follow the path prescribed at all times. Deviations will be continuously made to utilize favorable factors along the route of flight. Deviations of as high as a half a nautical mile would be common. Uncertainty of actual aircraft location would reduce prediction accuracy.

These factors suggest that the effect of terrain masking should be considered only where it is sure to occur due to very pronounced terrain elevation changes. A one nautical mile grid would be sufficient for resolving pronounced elevation changes of this type.

3.2.1.2 Developing the Scoring Function. Having Determined an appropriate flight path generation scheme, the next major step was to develop an analytical means for selecting which grid intersections provide the best path from starting point to target complex. The method selected was to use a multi-attribute decision analysis technique. The general idea was to construct a scoring function which could provide a value at each of the grid intersection points. The value need not have direct connection with a measurable phenomena at the point, e.g., radar cross-section but could instead subjectively measure the desirability of one point in the grid relative to all other points within the grid. The value being based upon the manner in which one point was found preferable to another by the mission planner. Once a value has been obtained for each point, a path can be found which will optimize the planner's preferences by either maximizing or minimizing the accumulated values. Whether the task is to maximize or to minimize the values is a function only of the sign of the values. In this study, it was decided that high positive values would indicate locations to be avoided. Therefore, the goal is to minimize the accumulated values of the points constituting the flight path.

A number of techniques have been developed for capturing and mathematically expressing a decision makers preference structure. Figure 3-1 provides a listing of the forms which

Scoring Models
1. Linear additive: $u = b_0 + \sum b_i x_i$ 2. Linear additive with interactions: $u = b_o + \sum b_i x_i + \sum b_{ij} x_i x_j$ 3. Linear additive with higher order functions: $u = b_o + \sum b_i f(x_i)$ Where: $f(x_i) = x_i^n$, Log x_i, etc. 4. Multiplicative: $u = b_o \prod x_i^{b_i}$

Figure 3-1

Mathematical Expressions of Preference Structures (7)

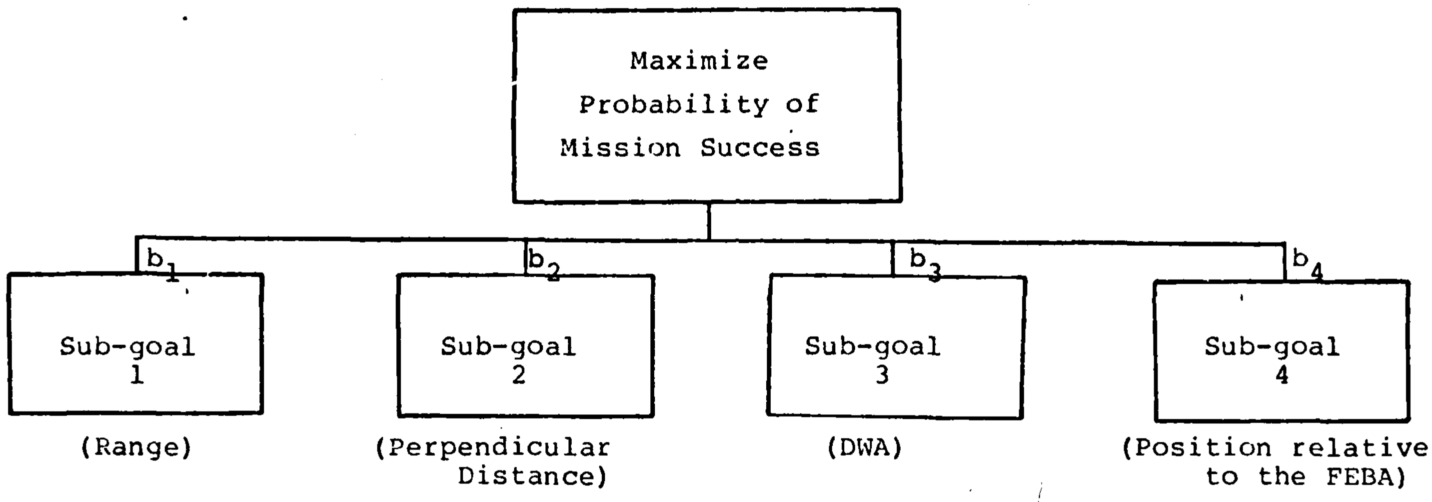
have most often been used in practice. In Figure 3-1, the x_1's represent the value of a particular factor (attribute) in the decision process and the b_1's represent the weighting of each factor in the overall scoring.

The procedure used to develop the desired scoring function was patterned after a combination of two techniques. The first, referred to as simple multi-attribute ratio technique, was suggested by Mark Edwards (2) and the second was presented by Sage (11) under the general heading of worth assessment. Both techniques use the linear additive form of the scoring function. In order to use this form, it is necessary to assume that the factors in the decision process are independent. Independence implies that the preference of one level of a factor to another level of the same factor is not influenced by the levels of other factors, i.e., that no interaction of factors exists in the decision process. It is suggested by Edwards (2) that incorrectly ignoring interaction effects introduces only small errors in the values obtained for competing alternatives and affects even less the ranking of the alternatives. Determining the coefficients of the interaction terms is very difficult for all but very simple models involving a small number of decision makers. Based on the above reasoning the authors felt justified in assuming independence for this feasibility study.

The first step in developing the scoring function was to construct a mission planning goal hierarchy. The purpose of the hierarchy was to provide a framework for determining the pertinent factors to be included in the model. Hierarchy

construction began with the mission planner's overall goal of selecting a flight path to the target complex which maximizes the chances of success. Sub-goals were then selected which contributed to this overall goal. Care was taken to ensure that sub-goals were consistent with the type and depth of information which a mission planner could reasonably be expected to have abailable. For example, it might be advantageous to favor defense locations which have lost direct contact with the command and control network, i.e., operating autonomously, but information of this type is not likely to be available to the mission planner. Therefore, including this as a sub-goal in the hierarchy would be of little benefit and would serve only to complicate the resulting model. It was equally important to ensure that no significant sub-goals were left out. The resulting hierarchy is illustrated in Figure 3-2.

It should be noted that terrain information is important in two sub-goals. Minimizing total exposure to suspected enemy air-defense locations necessitates the ability to consider the effects of terrain masking. This type of terrain information requires little explanation. However, maximizing terrain value may not be as clear of a concept. The type of terrain over which a flight is conducted has value to the pilot in addition to terrain masking. For example, flight over mountainous terrain reduces the chances of detection by air-defense systems due to ground clutter and may also increase the ability of breaking a defense system's tracking ability by maneuvering to obtain terrain masking. Flight



Sub-Goal

1 = Minimize exposure to potential air-defense systems

2 = Minimize exposure to major cultural features

3 = Maximize use of available terrain features

4 = Minimize exposure to enemy defense coverage

Fig. 3-2 Mission Planning Goal Hierarchy

over relatively flat terrain with little or no vertical development provides no such advantage to the pilot. It is likely therefore, that some types of terrain are preferred by the mission planner to others independent of information concerning potential air-defense locations. Another illustration of the terrain value concept is the use of ridge lines. In mountainous areas, it is frequently advantageous to fly parallel to ridge lines rather than perpendicular to them. In this manner, the aircrew maximizes ground clutter and maneuvering capability. This procedure is often times called, Flight Contouring. Therefore, within general types of terrain, for example mountainous or flat, there may exist preferred routings. The terrain value goal is intended to capture these preferences in the scoring function.

Although roads, cities and other man-made (cultural) features do not present a direct threat to a penetrating aircraft, the mission planner must consider the consequences of routing near them. In an environment of highly mobile air-defense systems, knowledge of all or even a small percentage of the total number of defense locations is highly unlikely. It is reasonable, however, to assume that defenses will be clustered along major transportation/communication links and near industrial and military centers. In addition, the probability of being detected by means other than air-defense systems increases as the level of activity on the ground increases. For these reasons, it is advisable for a

penetrating aircraft to minimize exposure to these types of locations. These considerations have been included in the function through the minimize exposure to cultural features sub-goal.

The last sub-goal on the second level is to minimize total exposure to the enemy. As the number of unknown air-defense locations increases, the desirability of spending additional time beyond the FEBA in an effort to minimizing exposure to suspected air-defense locations is reduced. If carried to an extreme, with no information concerning the mission environment, the flight planner would have a strong tendency to route the aircraft from the starting point to the target in a straight line in order to reduce the exposure to enemy controlled territory. This is never the case because at least some information is always known about the mission environment, e.g., terrain, cultural features. However, the goal to minimize total exposure to air-defense coverage is important anytime less than complete information is available.

At the lowest level of the goal hierarchy it was necessary to determine a measure (attribute) for the level of achievement for each of the sub-goals identified. When selecting these attributes, care had to be taken to ensure that the magnitude of the attribute was measurable by the mission planner. The process of selecting and defining the appropriate attributes was the most important step in the scoring function formulation.

As mentioned earlier a common measure used when determining exposure to air-defense systems is the weapon system's probability of kill (P_k) or, conversely, the aircraft's probability of survival (P_s). These measures are frequently expressed mathematically as:

$$P_s = (1-P_k)$$

and $P_k = P_d x P_{l/d} x P_{h/l} x P_{k/h}$

where: P_s = Probability of survival

P_k = Probability of kill

P_d = Probability of detection

$P_{l/d}$ = Probability of launch given detection

$P_{h/l}$ = Probability of a hit given a launch

$P_{k/h}$ = Probability of a kill given a hit

The probability that an aircraft will be detected (P_d) is a function of a number of factors. A simplified listing might be:

1. Range from the weapon system
2. Aircraft exposed radar cross-section
3. Terrain masking
4. Amount of ground clutter
5. Effectiveness of electronic counter measures (ECM) employed
6. Operational status of air-defense system

Each of these factors must be examined in the context of how a mission planner might view them. Range from a suspected air-defense location is information readily available to the planner as is the effect of terrain masking and ground clutter.

The aircraft exposed radar cross-section is a function of the angle between the aircraft center line and a straight line from the defense system to the aircraft (aspect angle) (Fig. 3-3). The planner would have this information available provided the aircraft was assumed to be flying the flight path segment straight and level. A more realistic view of the situation would be that the aircraft will be changing heading and altitude continuously to make use of terrain features and to reduce track determination capability. Therefore, aspect angle would be changing along a flight segment resulting in a continuously changing radar cross-section. It was felt that a mission planner would not have sufficient information concerning this factor to allow its use in the decision process. The planner would likely have an indication of the type of ECM equipment on the aircraft prior to initiating the planning task. Unfortunately, the effect that ECM has on air-defense systems depends on so many factors that accurate prediction without sophisticated simulation is unlikely. In addition, there is a feeling among many of the tactical mission planners interviewed that the mission planning process should be conducted without considering detection degradation by use of ECM. For these reasons, ECM was not considered to be a significant factor in the mission planner's decision process. Lastly, the operational status of the air-defense system was not included in the list of factors likely to be considered by the planner for obvious reasons.

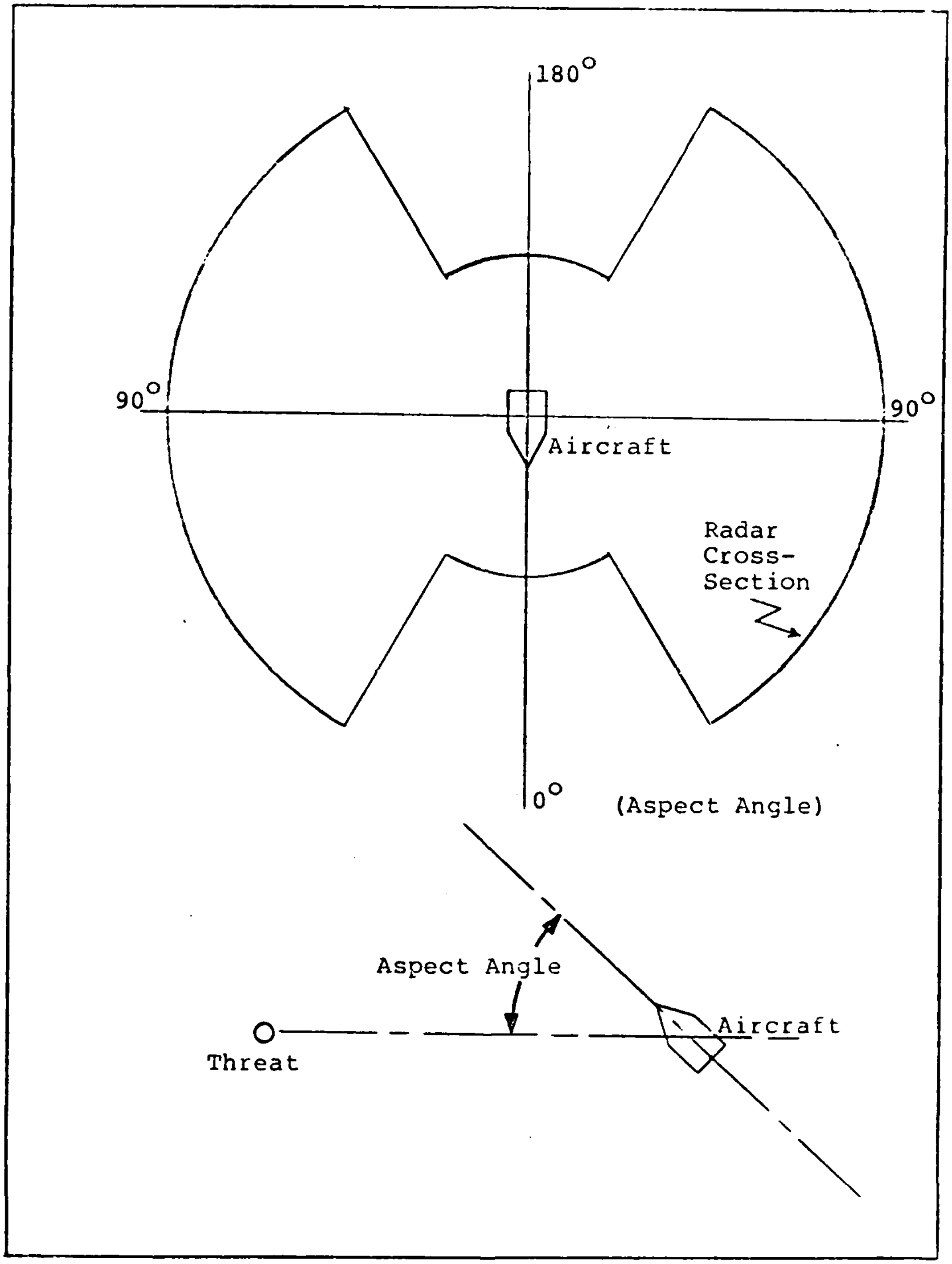


Figure 3-3

Typical Radar Cross-section vs. Aspect Angle Plot

The probability that a given air-defense location will fire on the penetrating aircraft ($P_{l/d}$) is primarily a function of the enemies command and control network and the operational status of the system. Information concerning these factors is not likely to be available to the planner. For this reason, it is assumed, during the planning process, that all defense locations have the same probability of launching a weapon at the aircraft if detected and $P_{l/d}$ can be arbitrarily given a constant value.

The probability of the weapon hitting the aircraft if it is successfully launched ($P_{k/l}$) depends greatly upon the type of guidance employed (if any), the range to the aircraft and aircraft characteristics, such as, speed and maneuverability. It was felt that information concerning each of these would be available and useful in the planning process.

Finally, the probability of destroying the aircraft given a hit on or near the aircraft ($P_{k/h}$) is a function of the type aircraft and type of air-defense weapon. Again, this information would be available to the mission planner and could be used in the decision process.

In summary, the factors which would be available to the planner concerning the probability of kill due to a particular air-defense location are:

1. Range
2. Degree of terrain masking
3. Air-defense system characteristics
4. Aircraft characteristics

The first factor, range, is important in both detection probability and in the probability of a hit given a launch. Mathematical functions relating each of these probabilities to range have been determined for most weapon system/aircraft combinations. A common method of expressing these relationships is by use of a weapon radius (R_w) for the weapon system. The weapon radius is defined as that radius at which as many aircraft survive within as are killed outside. Range was felt to be an appropriate attribute for determining exposure to enemy air-defenses.

Cultural features do not represent a direct threat to a penetrating aircraft. The danger associated with them is derived from the fact that ground activity tends to increase as they are approached. Increased activity results in a higher probability of encountering air-defense systems and increased chances of being detected, e.g., sighted by human observers. This suggests that an appropriate attribute for this sub-goal would be the perpendicular distance from the aircraft to the cultural feature.

Measuring the usefulness of terrain is a somewhat different problem. There is potentially an infinite variety of terrain that a mission might overfly. Unfortunately, a description of terrain does not form a convenient continuous measure. Types of terrain can be grouped into categories allowing a value to be given to each category describing its usefulness relative to all other categories. This value would then be a direct worth assessment (DWA) measure since it cannot be derived analytically from some other attribute, such as, distance.

The final sub-goal, minimizing total exposure to enemy defense coverage, is relatively straight forward. As the length of flight within the enemy's air-defense coverage is increased, exposure to unknown air-defense systems increases. The importance of this factor in the decision process is an indication of the certainty which the mission planner feels threats have been identified. The attribute that best measures this factor is the location of the aircraft relative to the forward edge of the enemy's air-defense coverage.

After determination of appropriate attributes for each of the sub-goals, it was necessary to determine relationships between these attributes and their value in the decision process. These relationships are frequently referred to as value functions. Functional relationships where established for three of the attributes. Terrain usefulness did not require a value function since it was a direct worth assessment.

Replacing the actual, but unknown, probability of kill function with the system's weapon radius results in a "cookie cutter" probability function (Fig. 3-4). This function is defined to have a value of zero for all points outside the weapon radius and one for all points within. Using this function instead of the actual distribution would result in predicting the same number of aircraft losses and is, therefore, an adequate approximation for this study. The "cookie cutter" probability of kill function assumes that the probability of launch given detection is one, the aircraft radar cross-section is constant regardless of aspect angle, and the aircraft does

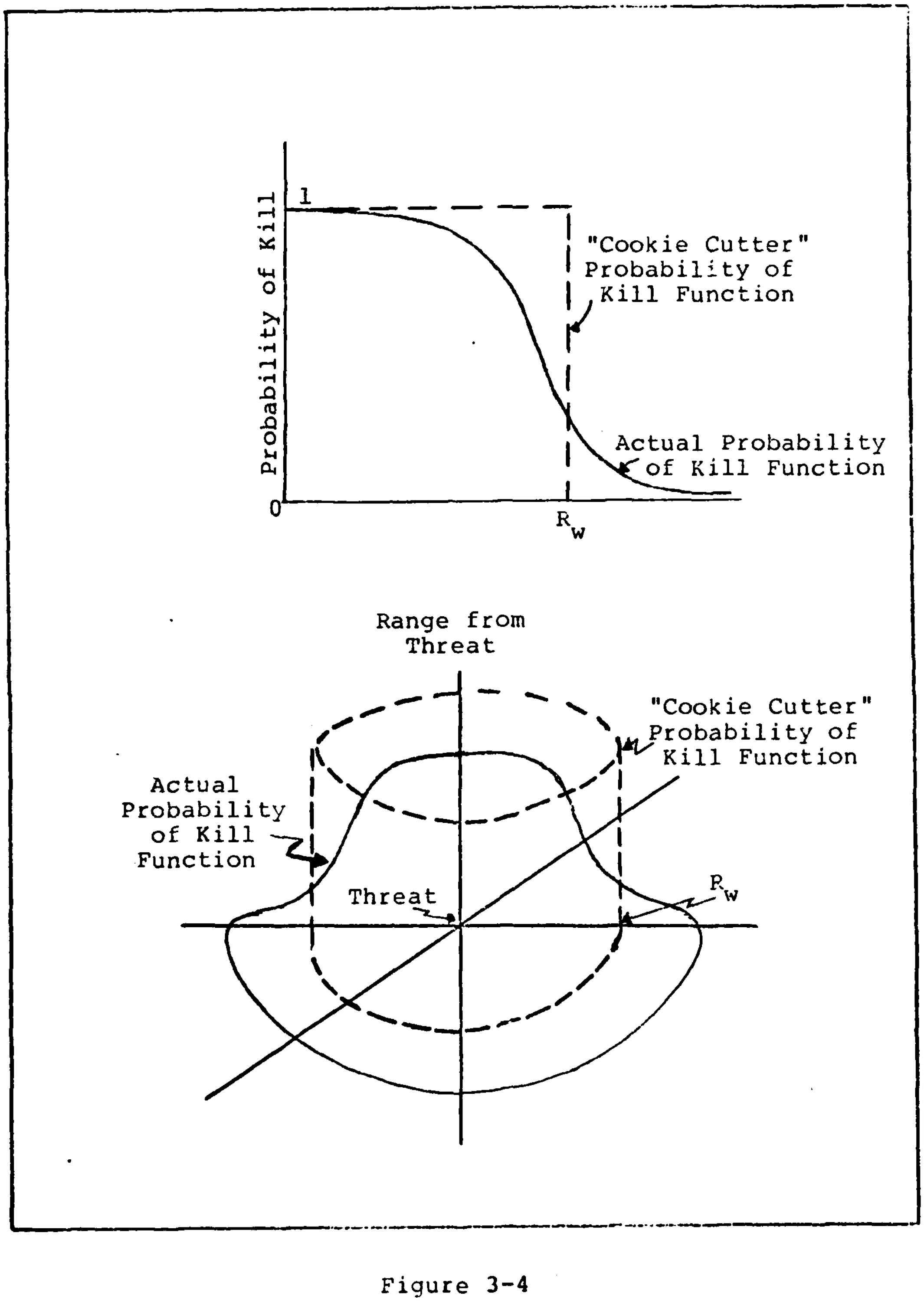


Figure 3-4

Relationship Between the Actual Probability of Kill Function and the "Cookie Cutter" Probability of Kill Function

not attempt evasive actions. For reasons discussed earlier, the first two assumptions are felt to be valid when modeling the mission planner's decision process. However, the last requires further investigation.

The ability to evade a given weapon system will be a function of many factors, such as, the weapon's size, speed, and turning ability. Unlike weapon radius, the effect of evasive tactics on probability of kill is a difficult concept to express analytically. For this reason, the mission planner must rely upon experience to subjectively assign each type of weapon system a value based upon its perceived threat to the aircraft relative to all other potential air-defense systems under consideration. In this manner, the mission planner can make trade-offs involving exposure to different types of air-defense systems in the decision process.

The value that an air-defense system has in the decision process is, then, a function of its weapon radius and the relative threat value assigned by the mission planner. Therefore, a separate value function must be constructed for each potential air-defense system. The general form of the function will be a step function with a value of zero if the range to the threat is greater than the weapon radius and equal to the relative threat value if not (Fig. 3-5). The value for exposure to air-defense systems for a point in the flight array is, therefore, the sum of the relative threat values for all air-defense locations which are within their weapon radius of the point and not terrain masked.

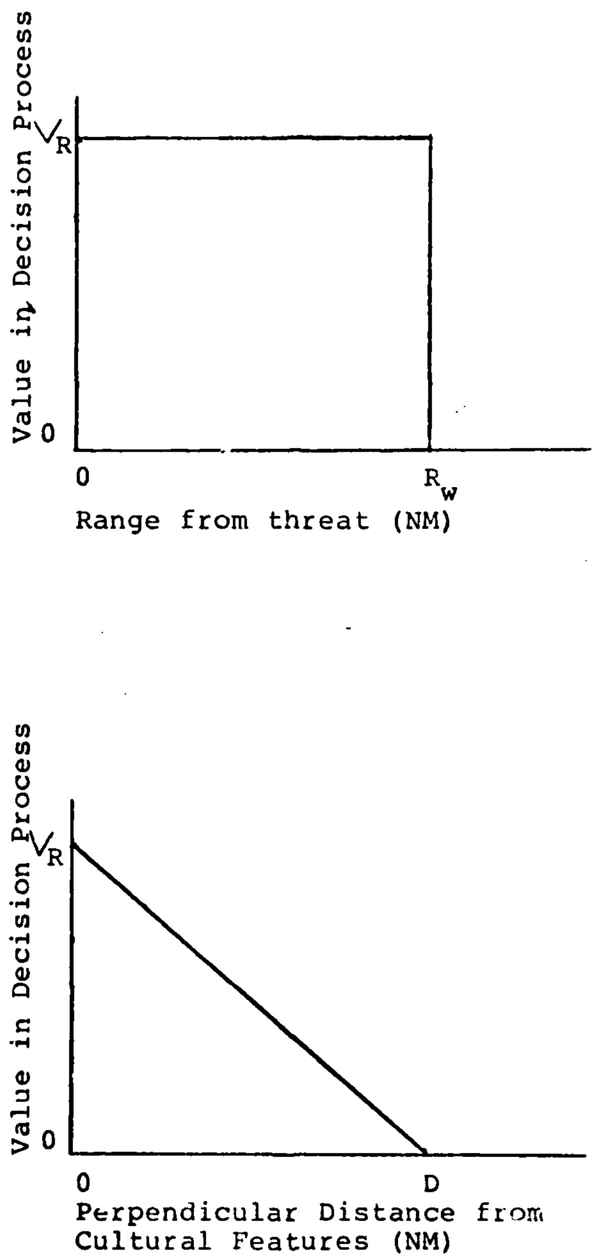


Figure 3-5

Typical Value Functions for Threat Exposure
and Exposure to Cultural Features

It is not possible to avoid all cultural features since they are homogeneously distributed over most land areas of interest. Emphasis was placed on only those features which were felt to have significant importance to the planning process. Three categories were selected for inclusion in the scoring function. These were:

1. Military installations
2. Major lines of communication (roads, railroads, etc.)
3. Major industrial/population centers

As in the case of air-defense systems, each type of cultural feature has a different relative value in the decision process. Unlike air-defense systems, types of cultural features cannot be considered independent. For example, military installations are frequently associated with major industrial/population centers and major lines of communication are nearly always found in major industrial/population centers. Therefore, when evaluating a given location only the most significant category of cultural feature was considered in the decision process.

The importance of a particular cultural feature to the mission planner can be expected to decrease as the distance from the feature increases. The exact shape of the curve representing this relationship will be different for each mission planner. Edwards (2) suggests that a linear approximation of the value function has generally provided adequate results in practice when dealing with multiple decision makers. Since the scoring function being developed is intended to represent the preference structure of many mission

planners, this approximation was felt warranted. The value function associated with a particular category of cultural features is defined as a straight line having a value equal to the relative value of the category at the feature and decreasing to zero at a distance (D) from the feature (Fig. 3-5). The distance (D) is the perpendicular distance from the feature at which the mission planner feels it no longer is important.

For reasons similar to exposure to suspected air-defense systems, the value function for total exposure to enemy air-defense coverage was determined to be a step function with a value of one for all points beyond the forward edge of the enemy's air-defense coverage. Anything beyond the FEBA entry corridor is considered to be within a region of potential enemy air-defense coverage.

The final step in formulating the scoring function was to determine the importance (weight) of the sub-goals and the relative value for the cultural features and air-defense systems. To accomplish this task, a questionnaire was used to elicite the necessary information from individuals experienced in tactical mission planning. When eliciting the relative value of different types of air-defense systems, actual systems were not identified. Instead, four categories of weapon systems were identified by characteristics, such as, size and turning ability (Table 3-1). It was felt that by identifying general characteristics of air-defense

TABLE 3-1

Air Defense System Categories

SAM NUMERICAL DESIGNATOR	MISSILE SIZE	LOW ALTITUDE CAPABILITY	MISSILE GUIDANCE	MAX G's REQUIRED TO DEFEAT
1	Medium	- 100 ft	Radar/optical	6.5
2	Small	- 100 ft	Radar/optical	GT 6.5
3	Small	- 100 ft	IR/tail only	5.0

AAA DESIGNATOR	RATE OF FIRE RND/MIN	ALTITUDE CAPABILITY	GUIDANCE	MAX G's TO DEFEAT
4	3500-4500	Sur-17000'	Radar/ Optical	Constant Maneuvering

weapon systems the scoring function would be applicable to a wider variety of scenarios. Nearly all air-defense systems of concern to the BAI mission planner can be placed within one of the categories provided.

The questionnaire was developed using a ratio technique described by Edwards (2). A sample of the questionnaire and the raw survey results are provided in Appendix A. Table 3-2 lists the sub-goal weights, relative values for each category of cultural feature with its effective distance, and the relative weights for each of the air-defense system categories used in the scoring function.

Having completed the above steps, it was possible to construct the scoring function. The final form of the function is:

$$V_{pt} = 0.25(0.82\Sigma T_1 + 0.99\Sigma T_2 + 0.45\Sigma T_3 + 0.82\Sigma T_4)$$
$$+ 0.25(0.88V_{c1}I_1 + 0.66V_{c2}I_2 + 0.99V_{c3}I_3)$$
$$+ 0.25(V_t) + 0.25(V_{ex})$$

Where: V_{pt} = Value associated with a point in the flight array

T_i = Suspected threat location type i

V_{ci} = Value of cultural feature category i

I_i = Index for cultural feature which is either 0 or i with a constraint the $I_i = 1$

V_t = Value of the terrain at the point

V_{ex} = 1 if point is subject to potential enemy air-defenses, 0 otherwise

TABLE 3-2

Weightings, Relative Values and Effective Distances from Elicitation Process

Sub-Goal Weightings	
Sub-Goal	Weight
b_1	.25
b_2	.25
b_3	.25
b_4	.25

Cultural Feature Relative Values		
Category	Relative Value	Effective Distance
1	.88	20 nm
2	.66	10 nm
3	.99	20 nm

Air-Defense System Relative Values	
Category	Relative Value
1	.82
2	.99
3	.45
4	.82

The model can now be used to score each intersection in the feasible flight region. The score at each point is representative of the mission planners preference for avoiding that point relative to all other possible points on the grid.

3.2.1.3 The Optimization Procedure. Before an optimization procedure could be developed, it was first necessary to clearly delineate the constraints affecting the feasible flight paths. Constraints can be subdivided into two types: (1) operational constraints, and (2) system constraints. Operational constraints are those factors which limit the possible number of alternative flight paths due to aircraft or mission characteristics. System constraints are those which are imposed to reduce the number of feasible alternatives for computational considerations.

Mission planners will not have complete freedom to cross the FEBA at any point desired. In order to distinguish between returning friendly aircraft and possible enemy strike aircraft, safe passage corridors will be established between friendly and enemy air-spaces. Aircraft entering enemy airspace on a strike mission will be required to pass through one of these corridors prior to crossing the FEBA. Therefore, the possible points of FEBA entry are limited to those points designated as safe passage corridors at the time of the mission. This reduces the possible number of feasible flight paths which must be evaluated for a particular mission.

The aircraft used in the BAI mission generally have limited fuel capacities. This restricts the total distance which the aircraft can travel on a particular mission. Other factors which affect the distance which can be traveled after passing the FEBA entry corridor are the distance traveled from the base of departure and the munitions loading. After considering these factors, a maximum range can be determined for the aircraft. Flight paths which exceed this maximum range are infeasible and need not be considered for evaluation.

It is tactically unwise to overfly the same location more than once on a mission. Doing so prolongs the length of the mission unnecessarily and alerts any enemy forces to the presence of an aircraft in the area which will lower the probability of survival. Therefore, feasible flight paths will pass between any two points in the grid a maximum of one time. This again reduces the total number of possible flight paths requiring evaluation.

Even with the operational constraints discussed above, the enumeration of all the feasible flight paths would be a time consuming task. Because of this, two additional system constraints were imposed. The first was that at no time could a move from one point to another result in the aircraft increasing the distance to the destination in the east-west direction (X-axis). The second required that the aircraft reduce the distance in either the east-west (X-axis) or north-south (Y-axis) directions on each move. For a sample mission of three nautical miles, the possible directions of move from the entry point are illustrated in Fig. 3-6. It

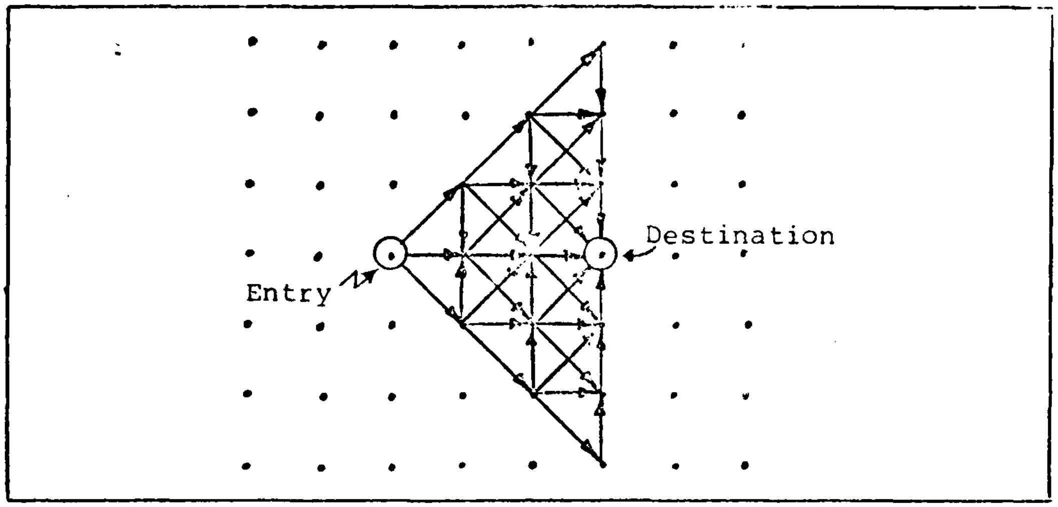


Figure 3-6

Possible Directions of Move in a
Three Nautical Mile Sample Mission

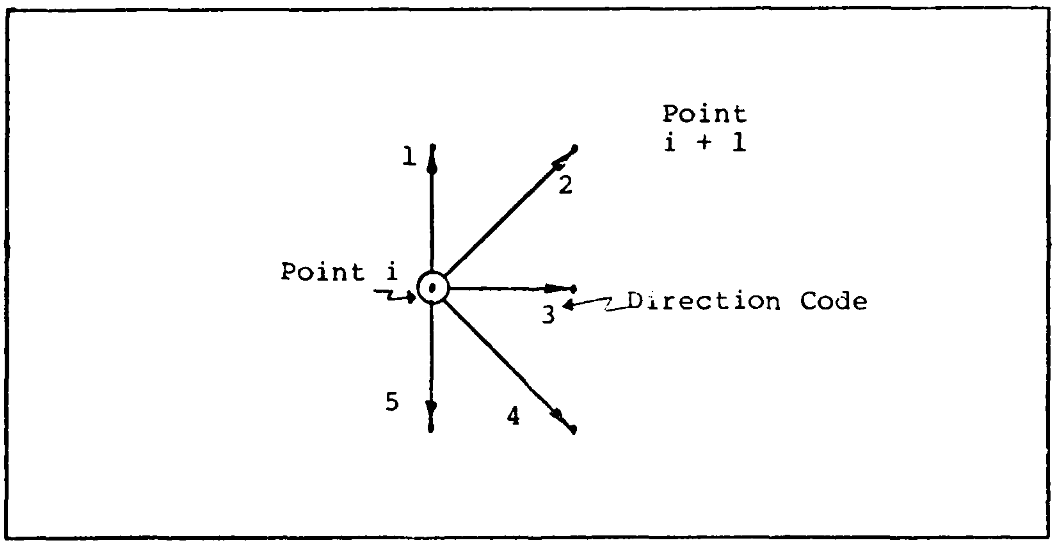


Figure 3-7

Possible Directions of Move From a
Point in the Feasible Flight Region
With Direction Codes

can be seen that the number of possible paths from entry to target even in this trivial case is large. The time required to enumerate and evaluate each possibility would become prohibitive as the problem grew to realistic dimensions.

Examination of Fig. 3-7 reveals that the possible paths from any point in the feasible flight region to the destination is independent fo the path followed in reaching the point. Therefore, the optimal path from the point to the destination can be found without considering previous moves. This is the Markovian property or principal of optimality which allows the formulation of a dynamic programming algorithm. Use of this approach provided an efficient method of determining the optimal path without requiring complete enumeration of all possible paths. Further information regarding dynamic programming is available from Reference 5.

The procedure requires that a value be placed at each point in the feasible flight region using the scoring function developed earlier. Since these values represent the relative preference for avoiding a point, the optimal path is the combination of points which has the lowest accumulated value. This can be expressed as:

$$\text{Min } V = \sum_{i=1}^{n} (VPT_i \times F(X_d))$$

where: VPT_i = The value of the ith point along a feasible path

n = The total number of points constituting a completed feasible path

V = The accumulated value

$F(X_d)$ = Correction factor for the increased distance traveled if point i is at 45^{o} to point i + 1

X_d = Direction of move from point i to point i + 1 (Fig. 3-7)

This expression is valid for the optimal path for the complete mission or for the optimal path from any intermediate point to the target. If an intermediate point is picked which has only one possible direction of move to reach the target, the accumulated value for the optimal path from that point to the target is equal to the value of the point. Similarly, the optimal path from any location can be determined if the minimum accumulated value for the points located in each of the possible directions of move are known. The optimal path corresponds to the direction from the point resulting in the lowest accumulated value. This can be expressed in the form of a recursive equation:

$$V^*_{xy} = \text{Min } (A \cdot VPT_{xy} + V^*(X_d))$$

where: V^*_{xy} = The minimum accumulated value from a point at coordinates (X,Y) to the target

VPT_{xy} = Value associated with point (X,Y)

$V^*(X_d)$ = The minimum accumulated value for the next point in direction X_d

X_d = The possible directions of travel from a point (Fig. 3-7)

A = Correction factor which accounts for the increased distance associated with moving at 45

$$\text{degrees} = \begin{cases} 1 \text{ if } X_d=1,3,5 \\ 1.4 \text{ if } X_d=2,3 \end{cases}$$

It is possible using this relationship to start at the destination coordinates ($V^*=0$) and work systematically back through the feasible flight region until the FEBA entry coordinates are reached. The points cannot, however, be evaluated randomly in this process since the minimum accumulated value for each point corresponding to the possible directions of move must have previously been evaluated. There are several patterns which can be used to systematically evaluate points which will ensure that this condition is satisfied. The pattern selected for implementation in this prototype system is pictured in Fig. 3-8 for the three nautical mile sample mission. This pattern was picked because it minimizes the number of points which must be evaluated to determine the optimal path.

All points in the feasible flight region need not be evaluated prior to initiating the optimization process. This is true because the constraints placed on the directions of travel result in portions of the feasible flight region becoming impossible to reach. For this reason, the value for a given point should be determined just prior to its being evaluated in the optimization process. This reduces the computer time required.

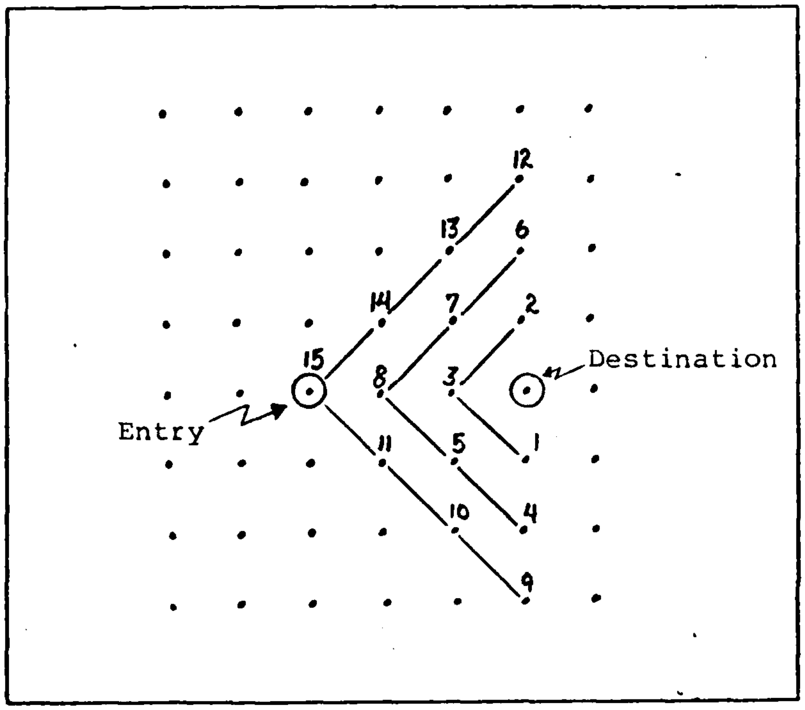


Figure 3-8

Selected Pattern for Systematically Evaluating Points in the Feasible Flight Region

When the point corresponding to the FEBA Entry Coordinates has been evaluted, the process stops since the accumulated value associated with the optimal path for the mission has been found. If the optimal direction of travel (X_d^*) is coded and stored with each point evaluated, the optimal route can be reconstructed. This is done by working forward through the grid starting at the entry point and moving in the coded direction for each successive point until the destination is reached.

3.2.1.4 The Computer Model. The prototype MADCAMP system was implemented on the CDC CYBER computer system using the remote terminal interactive capability. The use of the interactive capability provided a random access memory capacity approximately the same as a modern micro-computer. The computer model was formulated using FORTRAN IV computer language.

Fig. 3-9 provides the general flow diagram for the prototype system. The discussion which follows will concentrate on only those process blocks which have been numbered. The intent of the discussion is to provide the methodology used; not the details of the FORTRAN statements. The FORTRAN source code for the complete computer program is listed in Appendix B.

1. Input Mission Data:

The system was developed to minimize the amount of input data required and to provide the operator maximum planning

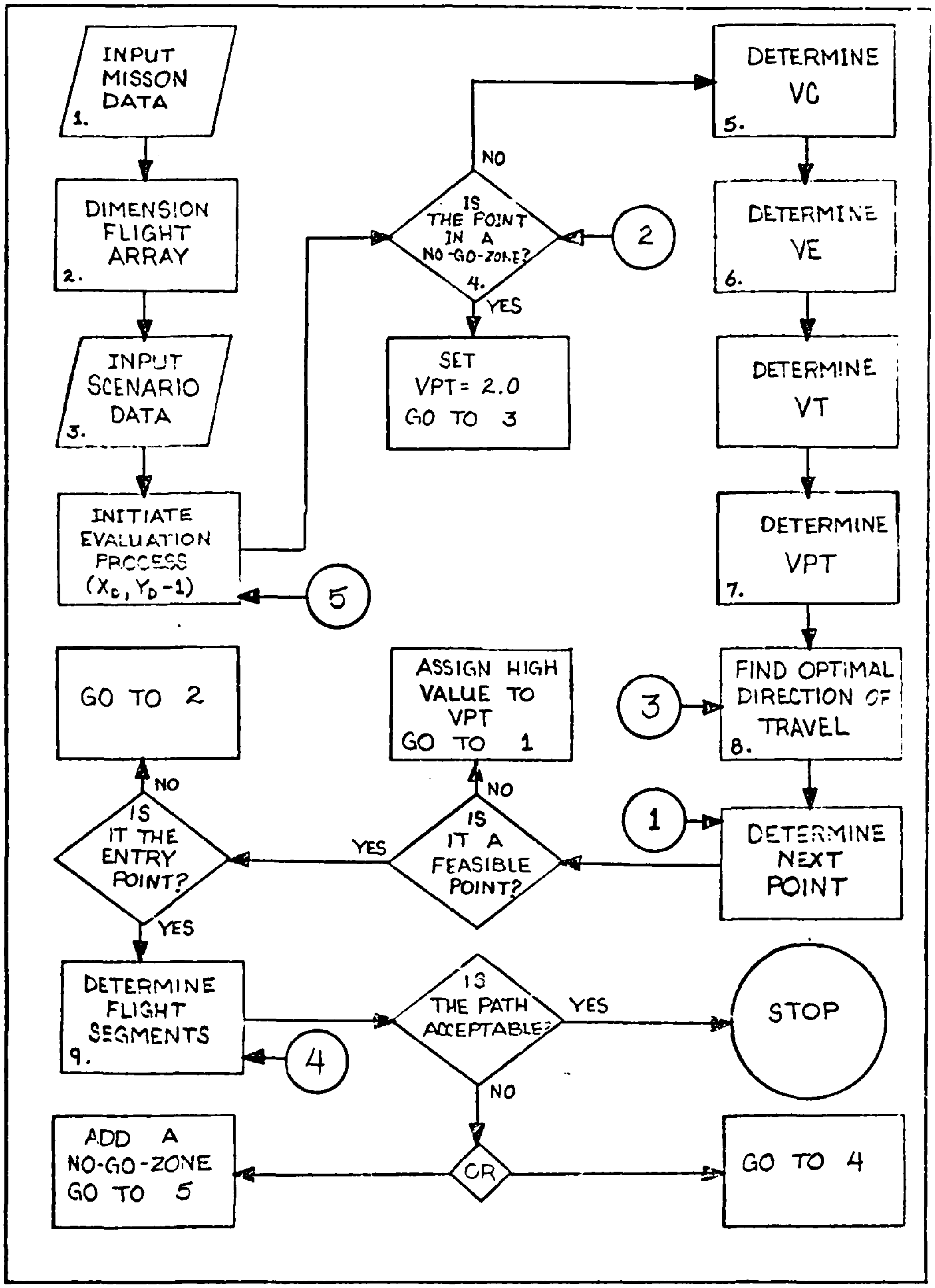


Fig. 3-9 MADCAMP System Flow Diagram

flexibility. The operator supplied input data required by the system are:

a. FEBA entry point coordinates (cartesian)

b. Weapon delivery initiation point (IP) coordinates (cartesian)

c. The aircraft's critical range (nautical miles)

d. The number of no-go-zones, coordinates (cartesian) and effective radius (nautical miles)

The FEBA entry point and IP coordinates are self explanatory and will not be discussed further. The concepts of aircraft critical range and no-go-zones require further explanation.

The system was developed to address only the portion of the overall mission between the FEBA entry corridor and the IP. The amount of maneuvering the aircraft can accomplish in this region is a function of the amount of fuel available at the entry point and the aircraft's fuel consumption characteristics. The aircraft must have sufficient fuel remaining at the entry point to reach the IP, accomplish the weapons delivery and to egress the combat zone. After considering each of these factors, it is possible to determine a maximum distance which can be traveled in transitioning from the entry point to the IP. This maximum distance is defined as the aircraft's critical range (CR) and constitutes a restriction to the feasible flight region.

Frequently a mission planner will have special restrictions applicable to a mission. Examples might be a search and rescue area or an area being subjected to heavy artillery

fire during the time which the mission is to be conducted. Such areas are usually to be avoided unless for very compelling reasons they must be overflown. Designation of no-go-zones provides a means for the operator to enter data of this type into the program logic. Other uses of this capability are:

a. It allows the operator to examine more than the optimal routing.

b. By placing a no-go-zone at the target coordinates the operator can insure the flight path will not cross the target enroute to the IP. (Note: this was the only use of this capability during the experimentation phase of the study).

2. <u>Determine the Dimensions of the Flight Array</u>:

Within the computer an mxnx2 data storage array is constructed. Conceptually the array corresponds to the one nautical mile grid which is used to generate the alternative flight plans. The purpose of the array, called the flight array (FM), is to store information obtained during the optimization process for the grid points in the feasible flight region.

To conserve computer storage requirements, the dimensions of the flight array, measured in nautical miles, are determined for each mission under consideration. A set of rules were developed which were designed to minimize computer requirements without unduly restricting operational suitability. The following rules are used by the program logic to size the flight array:

a. The m dimension is determined by adding one nautical mile to the X component of the destination coordinates and subtracting the X component of the FEBA entry coordinates. In no case is the dimension allowed to exceed 70 nautical miles.

$$IDX = \min (X_d+1-X_e, 70)$$

where: IDX = The m dimension in the flight array

X_d = X component of the destination coordinates

X_e = X component of the entry coordinates

b. The n dimension is determined by taking the absolute value of the difference between the Y component of the destination coordinates and the Y component of the entry coordinates and adding a maneuvering zone. The amount to be added for maneuvering depends upon the geometry of the mission. If the difference in the Y components is less than or equal to 20 nautical miles, a 30 nautical mile maneuvering zone is added to the n dimension of the flight array (Fig. 3-10). If the difference in the Y components is greater than 20 nautical miles but less than 40 nautical miles, a 10 nautical mile maneuvering zone is added (Fig. 3-10). Differences of greater than 40 nautical miles are not allowed which results in a maximum n dimension of 50 nautical miles.

$$\Delta Y = |Y_d-Y_e|$$

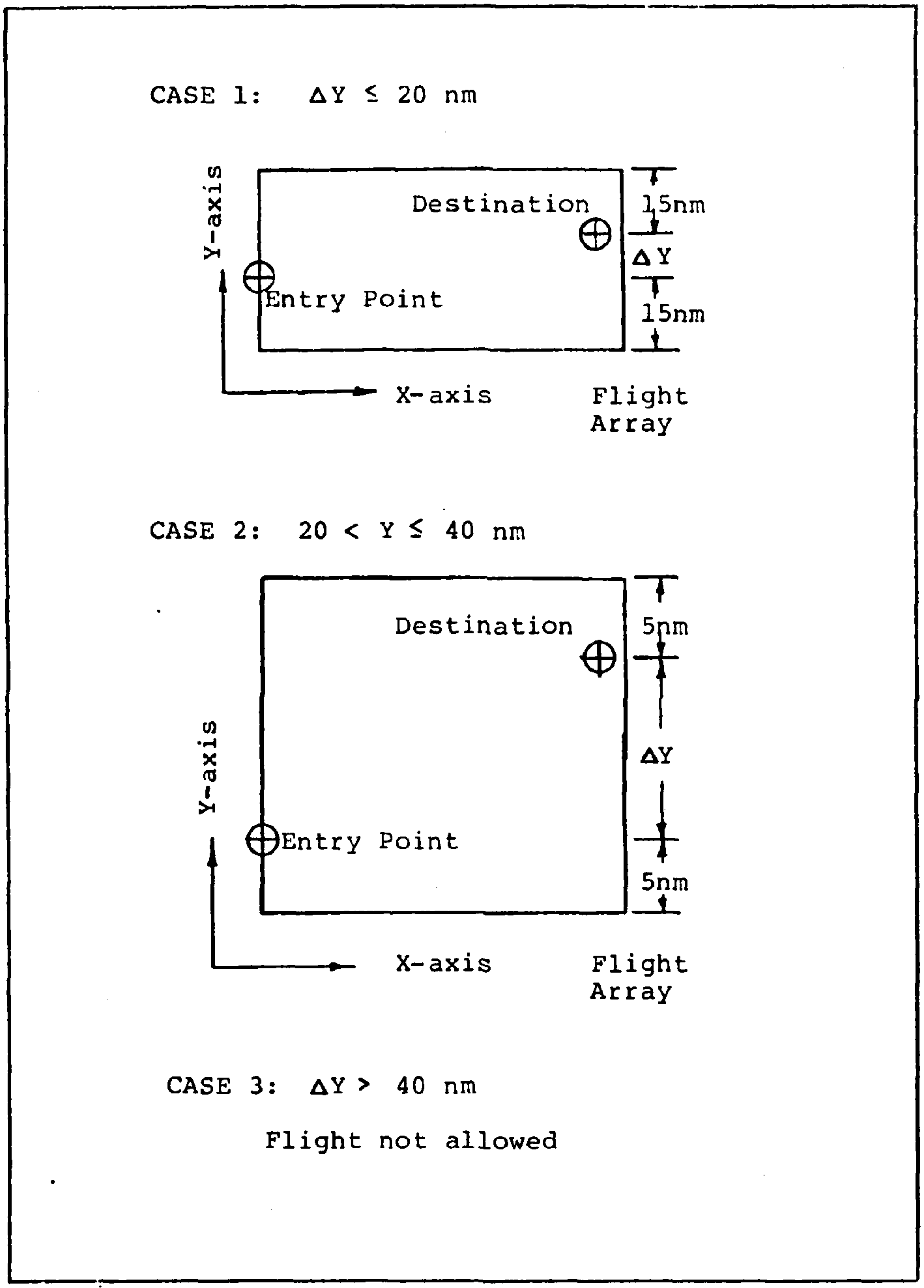


Figure 3-10

Rules for Dimensioning the Flight Array

(1) If $\Delta Y \leq 20$:

IDY = $\Delta Y + 30$

(2) If $20 < \Delta Y \leq 40$:

IDY = $\Delta Y + 10$

(3) If $\Delta Y > 40$:

Mission not allowed

where:

Y_d = Y component of the destination (IP) coordinates

Y_e = Y component of the entry coordinates

IDY = n dimension of the flight array

Data is stored in the flight array in the following format:

a. The accumulated value for the optimal routing from the point to the destination is stored in the first level of the array, i.e., FM (X,Y,1) as a single four digit integer number.

b. The accumulated distance from the point to the destination along the optimal path and the direction code to the next point along the optimal path are combined and stored in the second level of the array, i.e., FM (X,Y,Z) as a single five digit integer number.

3. Input Terrain and Threat Data:

The managing of the terrain data was a critical part of the overall system development. Two types of terrain data are required for each point in the feasible flight region. If this data were collected and stored for a 100 nautical mile square

area using a one nautical mile grid, a total of 20,000 computer storage positions (words) would be required. To attack this problem, two techniques were used which are referred to as selective terrain mapping and word coding.

When a mission planner is constructing a flight path, a terrain map of some type will normally be referred to determine the topography of the flight region. This information is used to derive information useful for evaluating terrain usefulness and potential terrain masking. The ability to predict terrain masking is a function of the elevation resolution of the map, the time allowed and the certainty with which the air-defense locations are known. As discussed earlier, each of these factors suggest that only significant terrain masking should be considered. Therefore, it may not be necessary to provide terrain information at the same level of resolution for all types of terrain. Sections typified by pronounced elevation changes (mountainous areas) would require greater resolution than sections having flat or gently rolling terrain. Two levels of resolution for terrain data were defined for this system. Terrain data is stored for a one nautical mile grid in mountainous sections where as mean terrain data over a ten nautical mile square is stored for less significant sections (Fig. 3-11).

Terrain data is stored in a 10 x 10 x (n+2) array, i.e., TR (10, 10, n+2). The last n levels of the array contain high resolution terrain data for each ten nautical mile square

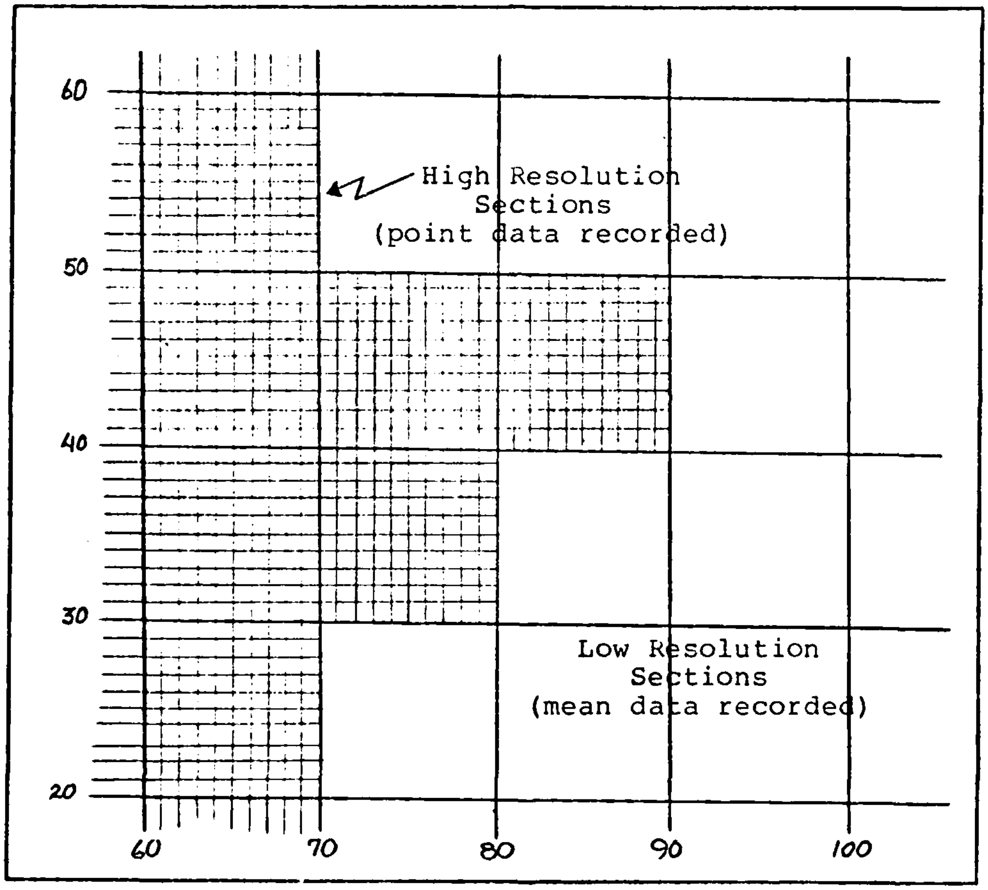


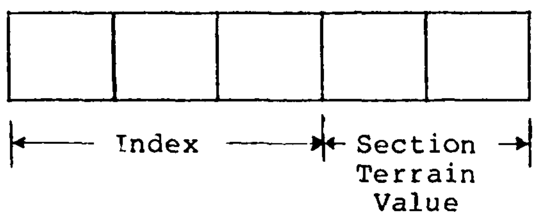
Figure 3-11

Typical Terrain Data Grid Showing
High and Low Resolution Sections

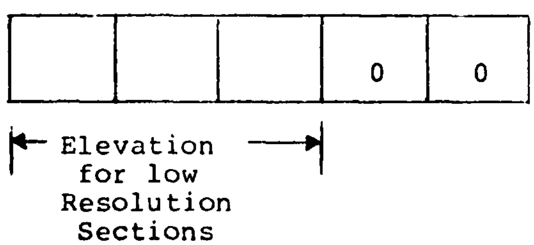
section felt to have significant terrain value or masking potential. The two additional levels are an index array and an array containing terrain data for the low resolution sections.

The data within the terrain array is coded so that a single five digit number (requires one sixteen BIT work) contains all of the information required for evaluation of terrain value and elevation for a point. The values are coded in the following manner:

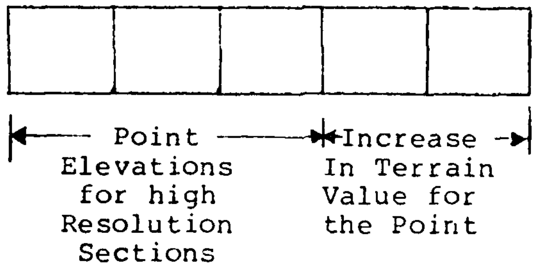
a. The first level of the array contains an index specifying the level of the array in which elevation data for a particular point is contained plus a general terrain value for the section in which the point is located.



b. The second level contains the mean elevation in hundreds of feet above sea level for the low resolution sections.



c. All subsequent levels of the array contain specific point elevations and terrain values for high resolution sections.



In addition to terrain elevations and value, the program also requires information concerning cultural features. This information is stored in two arrays which will be described in the discussion of block 6.

All information concerning a particular land area is stored on a single input file and is read into the computer for each mission plan. The program was designed in this manner to allow flight planning in any area. Although the prototype system was constructed specifically to handle 100 nautical mile square land areas, the size and shape is limited only by available computer storage.

A separate input file contains air-defense system location information obtained from intelligence sources. This information is read into the computer following the terrain input data. A separate input file is used to allow updating of intelligence data without affecting terrain data which is constant for a given area. The air-defense system location data is stored internally in the computer in an K x 4 array where K is the number of threat locations, i.e., TH (K_i 4).

For each suspected air-defense location, both X and Y coordinates, a relative threat value and weapons radius is provided. The use of this data will be further described in the block 7 discussion.

4. Is It Within a No-Go-Zone?

The first step in evaluating a particular point in the feasible flight region is to determine whether it is in a no-go-zone. The program sequentially checks the range to the center of each no-go-zone input by the operator and compares this to the effective radius of the no-go-zone. If the range to a zone is less than its effective radius, a large value (2.0) is assigned to the point and the process skips to the optimization phase. If the range is greater than the effective radius for each zone, the process continues with the determination of the point value (VPT).

5. Determine the Value for Cultural Features:

Two general types of cultural features were identified: 1) Point features such as cities and military installations, and 2) Linear features such as roads and railroads. Each type of feature is evaluated separately by the program and the results combined to provide a single value which is used in the scoring function.

For each point type cultural feature in the land area, the program stores its X and Y coordinates and relative value for use in the decision process. This information is obtained from the terrain input file and stored internally in an L x 3 array where L represents the number of point cultural features, i.e., CUL (L x 3). When evaluating a specific point

in the feasible flight region, a range (RC) is determined to each feature in the array. This range is used to determine a value for each feature using the following equation:

$$VC_i = (1 - \frac{RC}{20}i) \times VF_i$$

where:

VC_i = value of feature i at the point

RC_i = range from the point to feature i

VF_i = relative value of feature i

20 = the range of influence (nm)

From these values, the cultural feature with the maximum influence at the point is determined.

Values associated with linear cultural features are determined using a vector analysis approach. Roads and other linear features are approximated using straight line segments. These line segments are represented as vectors by storing the coordinates of their starting point, the changes in the X and Y coordinates to the termination point and a total length. This information is contained on the terrain input file and stored within the program in an P x 5 array where P is the number of linear cultural features, i.e., NR (P, 5). Each line segment (vector) within the array is tested to determine whether the point being evaluated is within its perpendicular boundaries (Fig. 3-12). This is done by constructing a second vector from the starting coordinates of the line segment to the point (Fig. 3-12). Two conditions

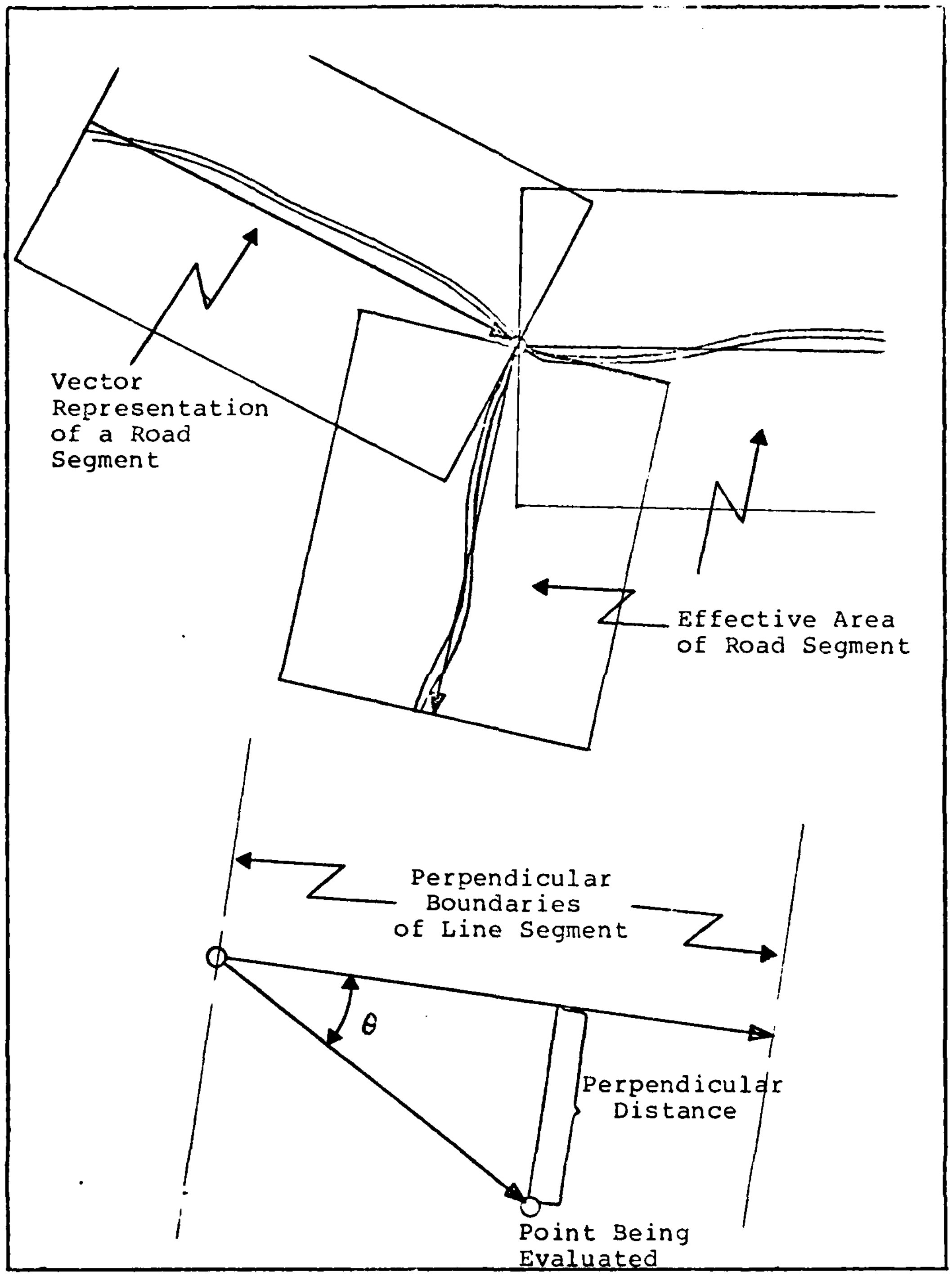


Figure 3-12

Geometry Used for Determining Value
for Linear Cultural Features

must be satisfied for a point to lie within the perpendicular boundaries of a line segment. The first requires that the angle between the two vectors be computed using the following relationship:

$$\cos\theta = \frac{|A|\ |B|}{A \cdot B}$$

$$A \cdot B = (\Delta X_a)\ (\Delta X_b) + (\Delta Y_a)(\Delta Y_b)$$

where:

$|A|$ = length of line segment A

$|B|$ = length of line segment B

ΔX_a = change in X coordinate along line segment A

ΔX_b = change in Y coordinate along line segment B

ΔY_a = change in Y coordinate along line segment A

ΔY_b = change in Y coordinate along line segment B

The second condition requires the calculation of the perpendicular distance (RP) from the point to a line extending the segment to infinity. This is done using the following equation:

$$RP = (\ |B|\ )\sqrt{1 - \cos\theta^2}$$

Where:

RP = perpendicular distance from the point to the line segment

Then if:

1) $\cos\theta \geq 0$, and 2) $|B|^2 + RP^2 \leq |A|^2$,

the point lies within the perpendicular boundaries of the line segment, and a value for the point can be determined using:

$$VR = .26 \times (1-RPmin/10)$$

where:

VR = the value of the point due to linear cultural features

RPmin = the minimum perpendicular distance between

10 = the range of influence (nm)

If these conditions are not met, the line segment has no influence on the point and the next line segment in the array is examined.

The cultural value (VC) for the point which is to be used in the scoring function is defined as the maximum between the values obtained from point features and linear features. In this manner, the value associated with the most significant cultural feature is determined for each point.

6. Determine the Threat Value:

The program assesses each suspected air-defense location in the threat array in sequence. For each point evaluated in the feasible flight region which is not within a designated no-go-zone, a straight line distance is computed from the point to the air-defense location and compared to the defense's weapons radius. If the point lies within the weapons radius, a test for terrain masking is performed.

In describing the scheme used to test for terrain masking, it is easiest to refer to Fib. 3-13. Two straight lines are drawn; 1) between the defense location coordinates and the point coordinates, and 2) between the air-defense elevation (considered to be z = 0) and the aircraft's elevation above the point (terrain elevation plus 200 feet) projected onto a reference axis. The slope of both lines is determined: the first being the location slope (MR) and the second being the elevation slope (MA). A determination is made as to whether the distance between the aircraft location and the air-defense location is greatest along the X or Y-axis. Regardless of the result, the procedure is essentially the same with two exceptions; 1) the axis which is used as the denominator to determine the range and elevation slopes and 2) the axis which is to serve as the reference axis. The disdussion which follows will assume that the greatest distance corresponds to the X-axis making this the reference axis.

The procedure starts at the threat coordinate and moves along the reference axis (X-axis) to the aircraft coordinate in one nautical mile steps. At each step, the Y coordinate is determined using the range slope and a line of sight (LOS) elevation is determined using the elevation slope. The X coordinate and the newly calculated Y coordinate are used to determine the elevation of the terrain. If the terrain elevation is greater than the LOS elevation, at any step, the aircraft is terrain masked. If the terrain elevation is less than the LOS elevation for all steps along the reference axis, the aircraft is not terrain masked and the value associated

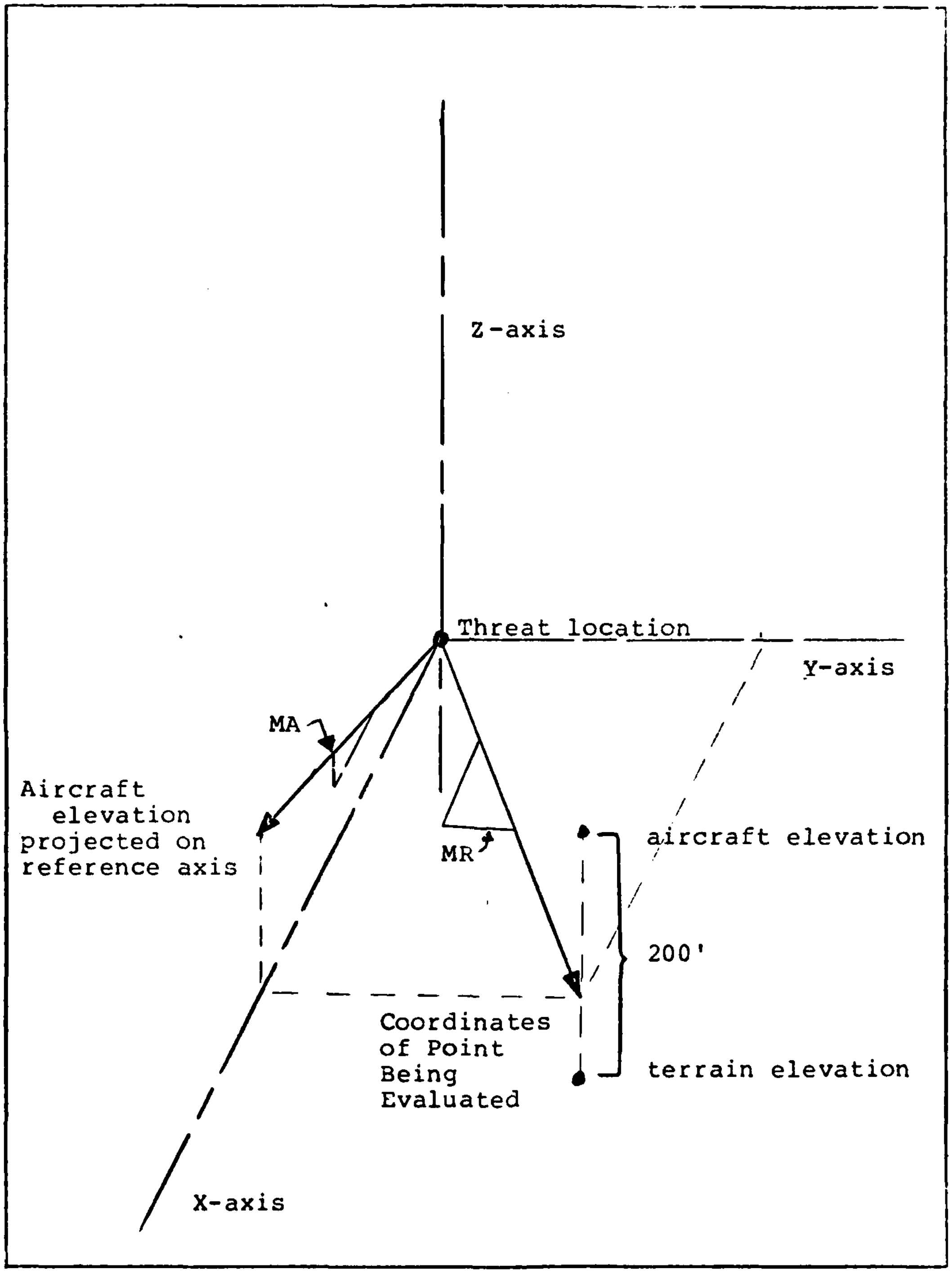


Figure 3-13

Geometry Used to Determine Terrain Masking

with the particular air-defense system is added to the accumulated threat value for the point. This process is continued until all of the locations contained in the threat array have been addressed. The resulting accumulated threat value is then stored for use in the scoring function.

There was a problem identified when determining masking in terrain sections which contain low resolution data. Because the elevation data in these sections are average elevations over a ten nautical mile square area, there may exist discontinuities of several hundreds of feet at their juncture. These discontinuities appear as vertical cliffs to the program and may result in terrain masking being predicted when in fact it is not probable. To prevent this from occurring, a scheme for eliminating these discontinuities was added to the program.

If either the air-defense location coordinates or the point coordinates are within a low resolution section, the elevation of the defense system and the aircraft are compared. When the air-defense system is higher than the aircraft, the aircraft's elevation is increased to that of the defense system. When the reverse is true, the air-defense system elevation is increased to that of the aircraft. This procedure reduces the chances of incorrectly predicting terrain masking and is consistent with the earlier determination to consider only significant effects.

7. Determine the Value of the Point:

The value associated with a particular point (VPT) is a weighted linear combination of the values obtained for threat exposure (VE), terrain value (VT), cultural value (VC), and distance traveled in the threat zone. The function relating these factors is:

$$VPT = VE \times .25 - VT \times .25 + VC \times .25 + .25$$

8. Determine the Optimal Direction of Travel:

To determine the optimal direction of travel, the point value obtained in process block 7 is added to the accumulated values associated with each of the possible directions of move. For 45 degree moves, the point value is multiplied by 1.4 to account for the greater distance traveled. The values are compared and the minimum is found.

The total distance from the point to the destination is computed for each of the possible moves using data available in level two of the flight array. In the event that there is not a single minimum accumulated value, the direction with the lowest total distance is picked as optimal. The total distance data is also used to ensure that the point is feasible. This is accomplished by adding the straight line distance (minimum distance) remaining to the entry coordinates to the accumulated distance along the optimal path. If the resulting distance is greater than the critical range for the aircraft, the point is not within the feasible region and a very large number is assigned as its accumulated value. This ensures that the point will not appear in the optimal flight path.

If the point is found to be feasible, the optimum accumulated value is entered into level one of the flight array and the total distance and direction code associated with the optimal path are stored in level two of the flight array. The program is now ready to evaluate a new point.

9. Determine Flight Segments:

The output of the system at this point is a curvilinear path which represents the optimal routing within the prototype system constraints. As mentioned earlier, such a flight path is not operationally acceptable due primarily to aircrew limitations. Therefore, it is necessary to approximate the output path with a series of straight line segments. It was felt that this process could best be accomplished by the operator. A computer model to determine the approximation would require considerable storage capacity and would reduce planning flexibility. The approach used provides the operator the final determination of the routing after considering the recommended path provided by the system.

10. Is the Path Acceptable?

After determining a set of flight segments, the operator may elect to enter the system again with the turnpoint coordinates. The computer system will evaluate the accumulated value for the path by approximating as near a straight line as possible between each selected turnpoint. The accumulated value derived will be higher than that provided by the optimal

routing. By changing the turnpoints, the operator can attempt to optimize the flight segments. This interactive capability allows the operator to introduce planning considerations beyond the capability of the computer system, for example, the selection of good landmarks for turnpoint recognition.

3.2.2 Scenario Development.

3.2.2.1 Test Area Selection. There were several impor- considerations in selecting a test area for evaluating the model. As a minimum, the area should contain terrain and cultural features representative of the categories considered essential to the mission planning process. The area should also provide a logical border for the establishment of a FEBA.

Several areas within the continental United States were considered. An area in the eastern part of the state of Washington was found to possess the necessary diversity of terrain and cultural features required to fully exercise the model. In addition, a major LCC running from the northwest to the southeast across the area provided an excellent boundry for establishing a FEBA.

3.2.2.2 Area Description. The area is bounded by coordinates 47-34-30N 121-28-00W to 47-34-30N 118-59-30W to 45-54-30N 119-01-00W to 45-54-30N 121-25-00W to point of origin (Fig. 3-14). The western one-third of the area is primarily mountainous, with high mountains with crisscrossing valleys in the north. Moving south the terrain elevation decreases and the valleys become more parallel. The central one-third of the area consists of low parallel ridge lines

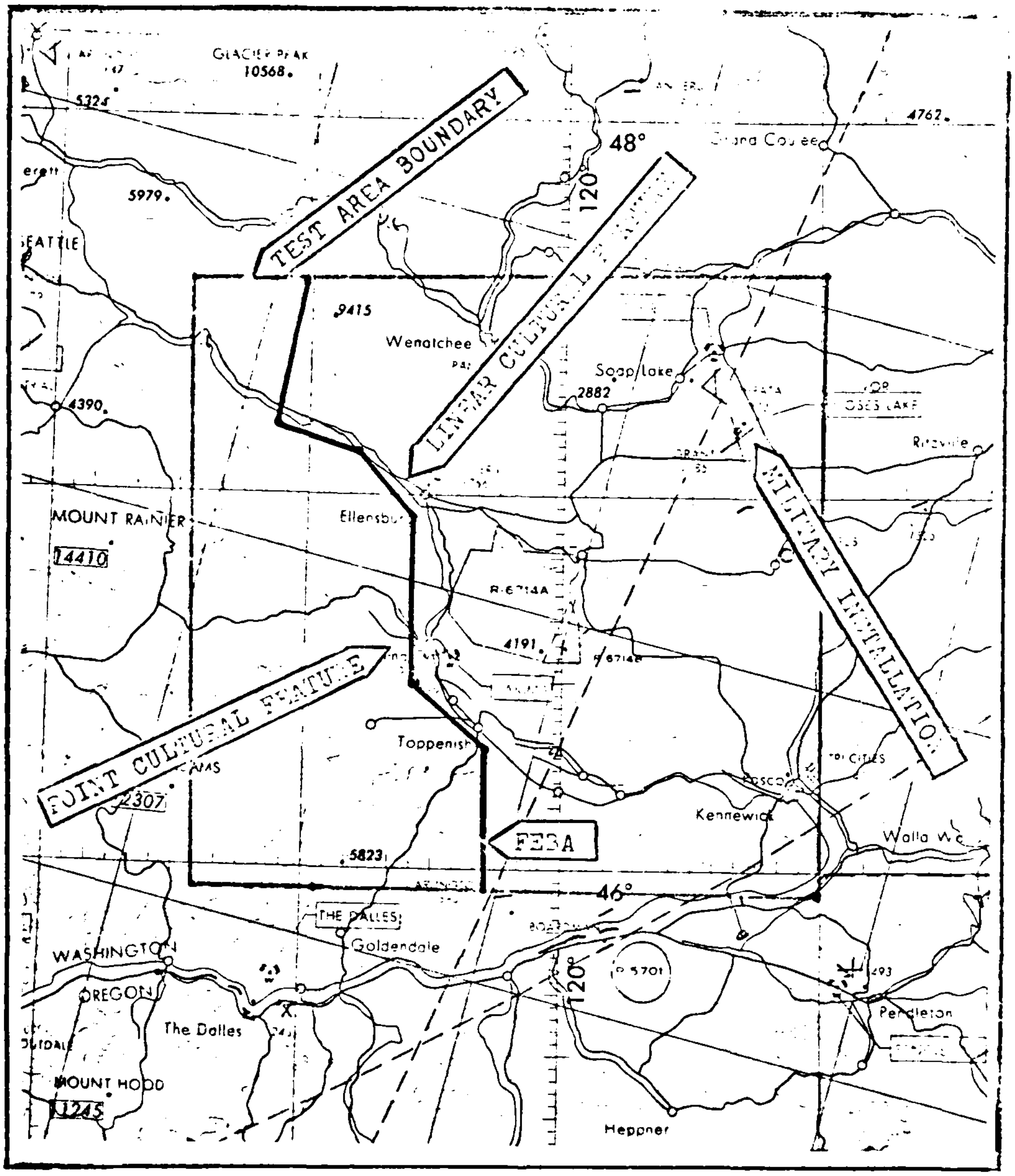


Fig. 3-14 MADCAMP Test Area

where the mountains and the flatlands merge. This section also contains several isolated ridge lines. The eastern one-third of the area is primarily flat or rolling terrain having very little vertical development.

In addition to the wide variety of terrain, the area also contains examples of the representative cultural features important to the mission planning process. There are two major LOCs crossing the battle area. The first, a major highway, runs west to east across the north central portion of the area. The second, a railroad and two major highways all running parallel, extends from the northwest corner of the area to the southeast corner. It is along the second LOC that a major portion of the FEBA was established. There are two major population/industrial centers, one in the center and the other in the southeast corner of the test area. The lowland, away from the major LOCs, is mostly farm land and rural communities. There are several large areas of near zero permanent population located throughout the mountainous areas. There is one major military installation in the north-east section of the area.

As a result of the wide variety of terrain and cultural features present, the area provides the capability to evaluate the model over the extremes of the conditions for which it was designed.

3.2.2.3 Threat Deployment. The threat deployment is based on a European type defense scenario. A FEBA was established along a major LOC running northwest to southeast between coordinates 47-34-30N 121-03-00W to 47-11-00N 121-07-30W to 47-06-00N 120-47-00W to 46-56-30N 120-35-00W to 46-30-30N 120-35-00W to 46-19-30N 120-18-00W to 45-54-30N 120-18-00W. The FEBA is 117 nm long and assumed to be defended by three Soviet air defense armies. It must be remembered that the test area is a 100 nm by 100 nm sector taken from the center of a larger battle area. The FEBA continues both north and south and has the same threat density as will be described for the FEBA within the test area. The battle area has been laid out with the enemy territory to the east of the FEBA.

In the test scenario, only highly mobile air defense systems were considered. As described earlier, the air defense systems were subdivided into four categories: medium size, radar/optically guided SAMs (Category I), small, radar/optically guided SAMs (Category II), IR guided SAMs (Category III), and AAA (Category IV). The missile size determination was based on the physical dimensions (length and diameter) and its warhead.

Based on a typical Soviet army defense deployment plan and missile capabilities, the SA-6, SA-8, SA-9 and ZSU-23-4 threats were determined to be the critical threats affecting high speed, low altitude penetration (Figures 3-15 and 3-16). Because of their guidance systems and missile size, the SAMs were categorized as follows (14):

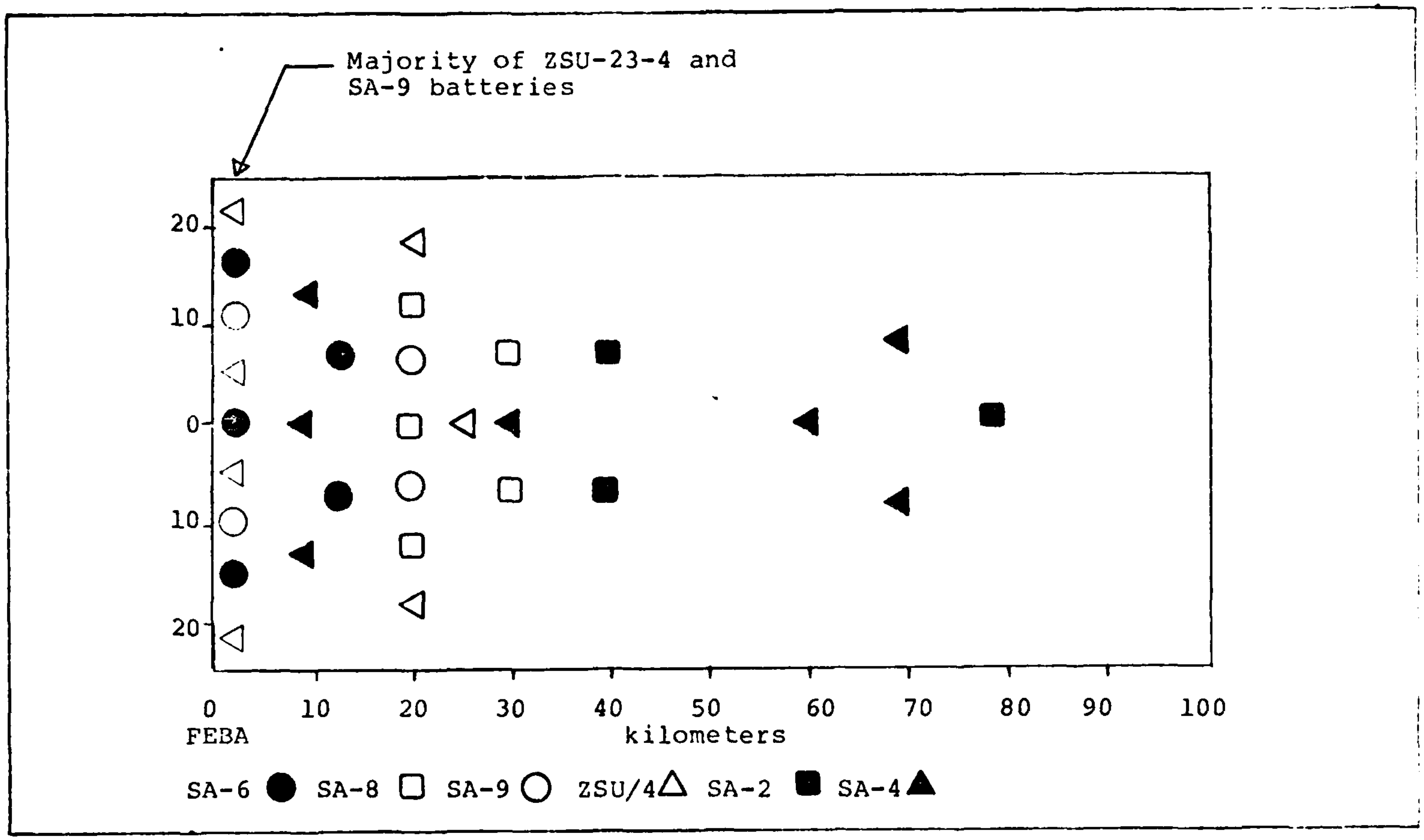


Figure 3-15

Typical Soviet Threat Deployment (10)

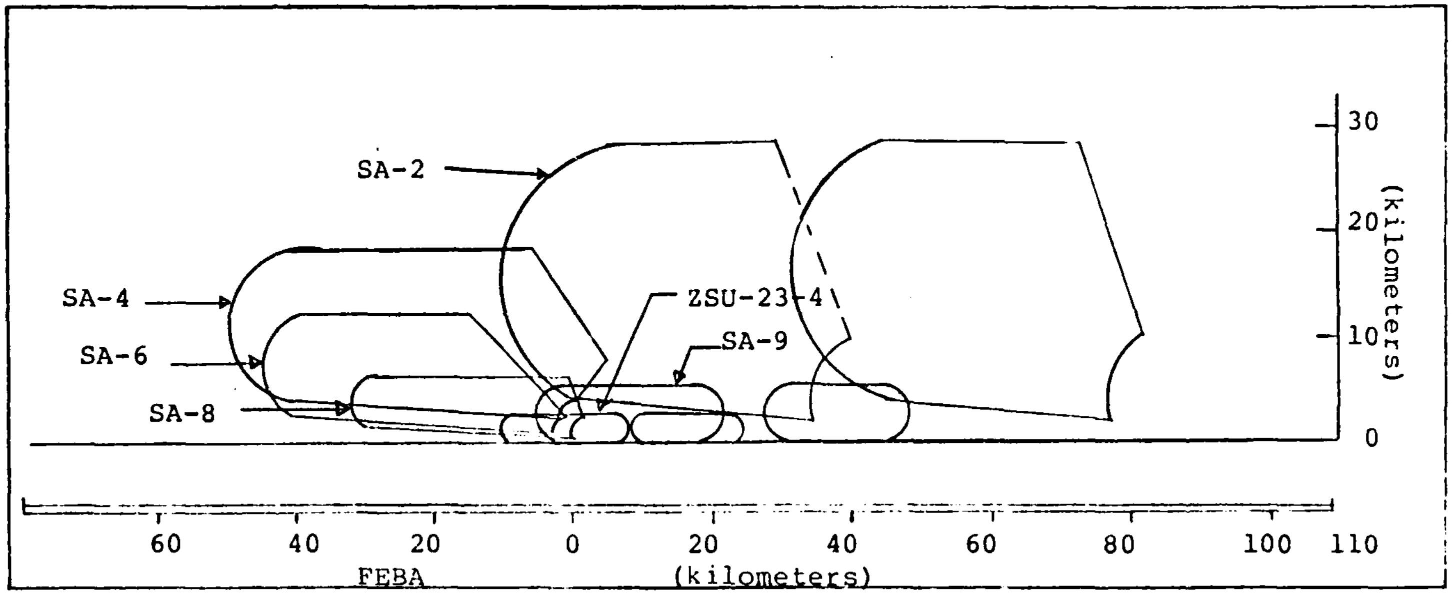


Figure 3-16

Soviet Air Defense Coverage (13)

1. The SA-6, a radar/optically guided missile with length 20 ft 4 in, diameter 1 ft 1.2 in and warhead weight of 176 lbs H.E. was placed in category I.
2. The SA-8, a radar/optically guided missile with length 10 ft 6 in, diameter 8.25 in, and warhead of 90-110 lb H.E. was placed in catagory II.
3. The SA-9 was placed in category III primarily because of its IR guidance.
4. The ZSU-23-4, a 23 mm mobile AAA system, was placed in catagory IV.

From the data presented in Fig. 3-16, a low altitude weapon radius was estimated for each of the four threats. The weapons and weapon radius are listed in Table 3-3. Using these weapons radii, the enemy can provide a solid, low altitude, air defense umbrella extending from 18 nm in front of, to 35 nm behind the FEBA. The majority of the mobile threats are deployed in a 16 nm band beginning at the FEBA.

Threat density is based on defense estimates for the West German FEBA (10). The mobile air defense weapon systems are organic to a division and each army comprises five to seven or more divisions. A typical Soviet air defense army make-up is presented in Table 3-3. It is estimated that there will be at least six and possibly ten armies in the first echelon defending the West German FEBA. (Unit size and numbers of weapons are based on 1975 data, any error will probably be on the low side.) Using a straight line approximation, the border between East and West Germany extends for

TABLE 3-3

Typical Soviet Army Mobile Air Defense Weapons (10, 13)

WEAPON	TYPE	UNITS (BATTERIES)	LAUNCHER VEHICLES	ESTIMATED WEAPON RADIUS
SA-6	SAM	5	15	18 nm
SA-8	SAM	5	20	5 nm
SA-9	SAM	64	256	5 nm
ZSU-23-4	AAA	32	128	2 nm

approximately 400 nm. If a total of ten Soviet armies are placed in defense of the 400 nm border, this provides a threat density approximately equal to that deployed along the FEBA in the test area, three armies per 117 nm.

Because of the highly mobile nature of the threats, the authors felt that, at any given time, the percentage of known threat battery locations would be small when compared to the total number of threat batteries present. The three armies entail a total of 318 threat batteries (Table 3-4). It was assumed that 50 threat battery locations are known and have been plotted within the test area. This leaves 84 percent of the batteries at unknown locations, all assumed to be within 16 nm of the FEBA. The majority of the known threat locations are along the FEBA in defense of enemy ground forces. These threats were positioned at points that, in the authors' opinion, held tactical significance, e.g., LOC choke points and major population/industrial centers. Moving deeper into enemy territory, the number of threat locations decreased rapidly. Here, the threats were in defense of bridges, power plants and a major military installation. In all cases the enemy defenses were positioned on the highest feasible terrain within the immediate area, providing the enemy maximum tactical advantage.

No air-to-air threat was considered in the threat scenario. Because of the high density of enemy ground threats in the FEBA area and the resulting command and control problems, the threat from enemy interceptor aircraft was assumed to be negligible.

TABLE 3-4

Total Number of Mobile Air Defense Systems Within the Test Area

WEAPON	TOTAL NO. DEPLOYED		NUMBER OF KNOWN BATTERY LOCATIONS	PERCENT KNOWN BATTERY LOCATIONS
	BATTERIES	LAUNCH VEH.		
SA-6	15	45	7	47%
SA-8	15	60	4	27%
SA-9	192	768	19	10%
ZSU-23-4	96	384	20	21%
TOTAL	318	1257	50	16%

3.2.2.4 Target and Entry Point Selection. A total of five targets and seven controlled entry points were designated throughout the test area. The targets and entry points were laid out to insure that the model was exercised over the entire test area; however, major emphasis was placed on exercising the model in the central region of the north/south axis. The actual targets are unimportant; since the route of flight was planned from one of three designated controlled entry points to a designated IP for each target.

The targets, IPs, and controlled entry points are listed in Table 3-5. The only target restriction placed on the model was a no-go-zone with a 2 nm radius located at the target. This was done to prevent over flight of the target and may result in an undesirable IP to target final turn in some cases. For this reason, the IP to target final turn should not be considered in the evaluation of the test, low-level routes.

The controlled entry points were positioned in friendly territory just outside of or at the extreme edge of the enemy, low altitude, air defense systems. The entry points were spaced at an average interval of 11.2 nm along the north/south axis. In an actual operational situation, great care would be taken in selecting low-level entry points to gain tactical advantage. However, for purposes of the evaluation, the entry points were positioned with the southern most entry point at grid coordinates 26-26 and the northern most at 15-93. The remaining five entry points were spaced at

TABLE 3-5

Target, IP, and Entry Point Coordinates

ROUTE	OPTIONAL ENTRY POINTS	IP	TARGET
1	(1,2,4)	46-32N 119-32W	46-30N 119-21W
2	(4,5,7)	46-58N 119-57W	46-56N 119-57W
3	(4,5,6)	46-58N 120-21W	46-58N 120-25W
4	(3,4,5)	46-48N 119-22W	46-49N 119-09W
5	(4,5,7)	47-16N 119-35W	47-19N 119-32W

ENTRY POINT	COORDINATES
1	46-19N 121-02W
2	46-24N 121-02W
3	46-39N 121-02W
4	46-47N 121-02W
5	46-58N 121-02W
6	47-09N 121-19W
7	47-18N 121-19W

randomly selected intervals, between 5 and 15 nm in length, along the north/south axis. This was done to eliminate the possibility of biasing low-level route selection by the computer model as a result of the entry point positioning.

3.2.3 The Experimental Design and Data Collection. The first step in evaluating the feasibility of the MADCAMP system was to clearly state the hypotheses which were to be tested. After stating the test hypotheses, procedures could be developed for collecting the necessary data which would allow statistical analysis to be conducted. A determination of the feasibility of the approach could then be made from the results of the hypothesis testing.

Two approaches to evaluating the feasibility of the MADCAMP system were felt to be appropriate. These were:

1. Operational acceptability
2. Preference structure simulation.

3.2.3.1 Operational Acceptability. The intent of the study was to determine whether a MADCAMP system could generate flight paths which are as operationally acceptable as those produced by experienced tactical mission planners. If the prototype system succeeded, a tactical pilot would be indifferent as to whether he flew a man-made or system generated flight path. This is the basis of the first test hypothesis.

The test hypothesis is:

H_o : Flight paths produced bv the MADCAMP system are at least as operationally acceptable as those produced by tactical mission planners.

The alternative hypothesis is:

H_a : Flight paths produced by the MADCAMP system are less operationally acceptable than those produced by tactical mission planners.

Not all tactical mission planners have the same experience. Therefore, it is conceivable that the flight paths generated by one mission planner would be different from another. Conversely, given flight paths from two different mission planners it is likely that different aircrews would have differing opinions as to which one was most preferrable. These differences of opinion can be expected when dealing with an environment exhibiting a high degree of uncertainty, such as, the BAI environment. If a group of aircrews were given the choice of several flight paths and they consistently picked one over the others, it would be safe to conclude that the one picked was more operationally acceptable than the others. With this in mind, the following procedure was devised for testing the null hypothesis.

The test scenario and missions described earlier were provided to the 388th Tactical Fighter Wing and its four F-16 squadrons weapon sections at Hill AFB, Utah. Each group was asked to choose the best combination of FEBA entry point and routing to the IP. The groups were briefed on the test scenario and given the following restrictions.

1. The aircraft critical range is limited to two times the straight line distance to the target.

2. The mission must cross the entry point on an easterly heading. Once past the entry point there was no restriction placed on headings.
3. The flight must be conducted within the boundaries of the test area.

At the same time, the five test missions were run on the prototype MADCAMP system. When accomplishing these computer runs, the interactive features of the system were not exercised. This was done so that the authors could not bias the results. The MADCAMP system outputs for each of the test missions are provided in Appendix C. Included on each output are the straight line approximations used to determine the turnpoints. Appendix C also lists the turnpoint coordinates for each of the flight paths provided by the tactical mission planners and the MADCAMP system.

For each test mission, the six flight paths obtained were plotted on a map. The naming of the paths was done using alphabetic characters which were assigned randomly. The maps were presented to eleven experienced tactical pilots and weapons officers stationed at Wright Patterson AFB OH and each was asked to provide an ordinal ranking for the paths from most preferred to least preferred for each test mission. In addition to the ordinal ranking, the aircrews were asked to score each path on a continuous scale ranging from 0 to 10 with 10 representing the most preferred path. Prior to scoring the test missions, they were provided the same scenario and restriction information given to the mission planners. The results of this testing are provided in Appendix D.

3.2.3.2 Preference Structure Simulation. Multi-attribute decision techniques attempt to capture in a mathematical function the preference structure of a decision maker, or decision makers, in order to aid them in choosing between alternatives. The more closely the scoring function used in the MADCAMP system simulates the preference structure of tactical mission planners, the more likely it will produce acceptable results in a variety of scenarios. Therefore, a second test of the feasibility of the MADCAMP system was to determine how well the scoring function simulated this preference structure. Therefore, the second test hypothesis is:

H_0 : The preference structure used by tactical mission planners is the same as that simulated by the MADCAMP scoring function.

the alternative hypothesis is:

H_a : The preference structure used by tactical mission planners is not the same as that simulated by the MADCAMP scoring function.

The first case examined was to compare the scoring function to the preference structure of the mission planners who produced the test missions. The method used was to score each of the six alternative flight paths using the scoring function developed for the MADCAMP system. If the accumulated values for each flight path were the same for a given test mission, this would indicate that although the paths were different the same preference structure was used to generate them. The results of this process are provided in Appendix D.

The second case examined, required the comparison of the MADCAMP scoring function with the preference structure of the aircrews doing the ranking. Since these aircrews were themselves experienced tactical mission planners, the degree to which their criteria is captured by the scoring function is also important.

To accomplish this, two rankings were obtained for each test mission; the first represented the ranking of each flight path determined by comparing the six mean scores provided by the aircrews (R_{1i}), while the second was determined by comparing the accumulated values provided by the MADCAMP system (R_{2i}). Appendix D provides the sets of rankings obtained for each of the test missions.

3.3 Analysis

The Statistical Package for the Social Sciences (SPSS) version 8.0 (8) was used to perform the following statistical analyses.

3.3.1 Operational Acceptability.

The first test hypothesis stated:

> H_0: Flight paths produced by the MADCAMP system are at least as operationally acceptable as those produced by tactical mission planners.

The alternative hypothesis is then:

> H_a: Flight paths produced by the MADCAMP system are less operationally acceptable than those produced by experienced tactical mission planners.

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A MULTI-ATTRIBUTE DECISION ANALYSIS APPROACH TO THE DEVELOPMENT--ETC(U)
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These can be expressed mathematically as:

$$H_o: \bar{S}_{1i} \geq \bar{S}_{2i} \text{ for all } i$$

and

$$H_a: \bar{S}_{1i} < \bar{S}_{2i} \text{ for at least one } i$$

where:

$\bar{S}_{1i}$ = mean score for the MADCAMP system generated flight path on test mission i

$\bar{S}_{2i}$ = mean score for the tactical mission planner generated flight paths on test mission i

A T-test was performed on the relative score data obtained during the experimentation phase. The results of this test for each test mission are provided in Table 3-6. A negative T-value indicates that the mean score for the MADCAMP system generated path was lower than the mean score for the paths produced by the tactical mission planners. The test results indicate that in all five test missions the MADCAMP system generated paths were either equally preferrable or more preferrable to the rankers than those produced by the tactical mission planners at a confidence level of 95% (α = .05).

In performing the T-test it was necessary to make a number of assumptions concerning the test data. Among these were:

1. The flight paths produced by the tactical mission planners were all operationally acceptable.
2. The relative scale used by the rankers for scoring the flight paths were all the same.

In order to investigate the validity of these two assumptions a second analysis was performed on the data.

TABLE 3-6

Results of T-Test on Relative Rankings by Test Mission

TEST MISSION	T VALUE	DEGREES OF FREEDOM	1-TAIL SIGNIFICANCE	STATISTICALLY SIGNIFICANT AT 95%
1	- .77	64	.223	No
2	-1.02	64	.155	No
3	1.33	64	.094	No
4	2.81	64	.003	Yes
5	3.10	64	.001	Yes

The scores provided by the rankers for each test mission can be expressed as:

$$S_{ij} = \mu + B_i + T_j + E_{ij}$$

where:

S_{ij} = score given to flight path j by ranker i

μ = mean score for all rankers and flight paths

B_i = the ranker effect

T_j = the flight path source effect

E_{ij} = random error effect

If the variance in the score can be explained by the ranker and random error effects, then the source of the flight paths would not be significant and the sources can be assumed to be equal. Therefore, the test hypothesis becomes:

H_o: $T_j = 0$ for all j

and

H_a: $T_j \neq 0$ for at least one j

One method of removing the variance in the scores due to differences in scales used by the rankers is to replace the relative scores by the ordinal rankings. This, in effect, forces each of the rankers to use the same scale. Unfortunately, this destroys the independence required by most parametric tests. The Friedman Two-way analysis of variance by ranks (3) provides a means for determining the significance of the source effect in this situation. The test statistic used is:

$$F = \frac{12\sum_{j=1}^{n} R_j^2}{kn(n+1)} - 3k\ (n+1)$$

where:

F = test statistic

R_j = the sum of the rankings for the jth source

k = the number of rankers

n = the number of sources

For values of n greater than seven the test statistic is closely approximated by the chi-square distribution.

The results of applying the Friedman test to the ordinal rankings obtained during experimentation are given in Table 3-7. It can be seen from these results that there is a significant (α = .05) source effect in three of the test missions. In two of these cases, the MADCAMP generated flight path received the highest mean ranking. However, in the third case (test mission two) the MADCAMP system received a mean ranking which placed it fourth from the highest ranked flight path.

A second method of removing the effect of the scale used by the rankers is to perform an analysis of variance on the relative scores while blocking on the ranker effect. (For a complete explanation of this technique see Ref. 4.) This was accomplished using SPSS by doing a two-way analysis of variance on the relative scores with source and ranker as the two factors. The results are provided in Table 3-8.

TABLE 3-7

Results of Friedman Test Applied to the Ordinal Rankings by Test Mission

Flight Path Source:	1	2	3	4	5	MADCAMP
TEST MISSION - 1						
Mean Rankings	4.00	3.09	3.64	2.82	3.55	3.91
CHI-SQUARE	SIGNIFICANCE		SIGNIFICANT AT 95%			
3.364	.644		No			
TEST MISSION - 2						
Mean Rankings	4.18	2.82	2.73	2.18	5.00	4.09
CHI-SQUARE	SIGNIFICANCE		SIGNIFICANT AT 95%			
18.429	.002		Yes			
TEST MISSION - 3						
Mean Rankings	2.64	3.27	3.27	3.82	5.36	2.64
CHI-SQUARE	SIGNIFICANCE		SIGNIFICANT AT 95%			
16.247	.006		Yes			
TEST MISSION - 4						
Mean Rankings	3.27	3.36	3.45	3.55	4.82	2.55
CHI-SQUARE	SIGNIFICANCE		SIGNIFICANT AT 95%			
8.558	.128		No			
TEST MISSION - 5						
Mean Rankings	5.00	3.36	4.18	2.55	3.73	2.18
CHI-SQUARE	SIGNIFICANCE		SIGNIFICANT AT 95%			
17.078	.004		Yes			

TABLE 3-8

Results of Two-Way ANOVA on Interval Preference Rankings

EFFECT	DF	F	SIGNIFICANCE	SIGNIFICANT at 95%
TEST MISSION - 1				
Flight Path Source	5	4.315	.769	No
Rankers	10	8.412	.464	No
TEST MISSION - 2				
Flight Path Source	5	4.175	.003	Yes
Rankers	10	.637	.775	No
TEST MISSION - 3				
Flight Path Source	5	4.229	.003	Yes
Rankers	10	.799	.630	No
TEST MISSION - 4				
Flight Path Source	5	2.302	.059	No
Rankers	10	.796	.633	No
TEST MISSION - 5				
Flight Path Source	5	4.336	.002	Yes
Rankers	10	1.609	.131	No

It can be seen that the results of this testing agree with those obtained by the Friedman Test. Since the ranker effect was insignificant (α = .05) in all five cases, a test of significance between individual sources can be accomplished.

The Newman-Keuls range test (4) was used to compare the sources in each of the test missions. A significance of .05 (α = .05) was chosen for the test. The results are provided in Table 3-9. In this table, sources which appear in the same subset are not statistically different at the significance level chosen.

The results of the Newman-Keuls range test agree with both the T-test and the Friedman test. These tests indicate that the preference for the MADCAMP system generated flight path was either equal to or greater than any of the tactical mission planner generated flight paths for each of the five test missions. Therefore, the test hypothesis cannot be rejected at a significance level of .05.

3.3.2 Mission Planner Preference Structure Simulation. The degree to which the scoring function used in the prototype MADCAMP system captures the tactical mission planner's preference structure is an important consideration in determining the feasibility of the approach. Two methods were used to investigate this. The first compared the scoring function to the preference structure of the mission planners while the second addressed the rankers.

TABLE 3-9

Results of Neuman-Keuls Range Test on
Relative Scores by Test Mission

TEST		FLIGHT PATH SOURCE					
MISSION	SUBSET	1	2	3	4	5	M
1	1*	X	X	X	X	X	X
2	1	X				X	X
	2	X	X	X			X
	3*		X	X	X		X
3	1					X	
	2*	X	X	X	X		X
4	1	X	X	X	X	X	
	2*	X	X	X	X		X
5	1	X	X	X		X	
	2		X	X	X	X	
	3*		X		X	X	X

* - Subset containing highest ranking source

In order to test the hypothesis that MADCAMP simulates the preference structure of experienced mission planners, the relationship between the accumulated values obtained for each flight path and the source of the flight path must be determined. The accumulated values for a flight path can be expressed as:

$$V_{ij} = \mu + T_i + B_j + E_{ij}$$

where:

V_{ij} = accumulated value obtained for flight path i on test mission j

μ = mean accumulated value

T_i = source effect

B_j = test mission effect

E_{ij} = random error effect

The test hypothesis is:

$$H_o : T_i = 0 \text{ for all } i$$

and the alternative is:

$$H_a : T_i \neq 0 \text{ for at least one } i$$

A two-way analysis of variance was performed on the accumulated values form Appendix D with test mission and source as the two factors. The results are provided in Table 3-10. The results indicate that there is a significant (α = .05) mission

TABLE 3-10

Results of Analysis of Variance on Accumulated Value by Source and Test Mission

EFFECT	F VALUE	SIGNIFICANCE (α)	SIGNIFICANT at 95%
Test Mission	7.244	.001	Yes
Flight Path Source	2.037	.117	No

effect while the source effect was not significant. Therefore, the test hypothesis that the preference structure used by the mission planners and that simulated by the MADCAMP system scoring function are the same cannot be rejected.

In the second case the test hypothesis can be expressed mathematically as:

$$H_o: \; R_{1i} = R_{2i} \quad \text{for all } i$$

and the alternative is:

$$H_a: \; R_{1i} \neq R_{2i} \quad \text{for at least one } i$$

where:

R_{1i} = ranking from the rankers for source i

R_{2i} = ranking from the MADCAMP system for source i

A Spearman rank correlation test (3) was performed on the sets of rankings for each test mission. The results of this testing are provided in Table 3-11. These results show all the correlations were positive although none of the correlations were statistically significant ($\alpha = .05$). It should be noted that a non-significant correlation would not be surprising since earlier analysis has indicated that the flight paths were generally not significantly different as far as preference. Therefore, any ranking of them using mean scores would not be very meaningful. It is intersting to note, however, that two of the three test missions which showed significant source effects had the highest positive correlations. These results

TABLE 3-11

Results of Spearman Rank Correlation
by Test Mission

TEST MISSION	CORRELATION R	SIGNIFICANCE	SIGNIFICANT AT 95%
1	.143	.394	No
2	.086	.436	No
3	.714	.056	No
4	.429	.199	No
5	.600	.105	No

are consistent with those obtained earlier with the mission planners. Therefore, the test hypothesis that the preference structure used by the rankers is the same as that simulated by the MADCAMP system scoring function cannot be rejected.

4 Conclusions

A review of the study in context of the original problem statement has lead to the following conclusions concerning the feasibility of the MADCAMP system.

1. The ability to generate tactically acceptable mission plans using a multi-attribute decision scoring function has been clearly demonstrated. The automation of the mission planner's decision process can provide acceptable flight plans in minutes rather than the hours which may be required to accomplish the process by hand. In addition to a considerable time savings, the quality of the resulting flight path's would not be greatly affected by the experience level of the aircrews. This fact would result in a higher overall quality of mission plans produced by an operational squadron. Carried to an extreme, a well trained technician could produce the flight paths thus allowing the aircrews additional time to perform other mission essential tasks.
2. Use of linear additive scoring function, selective terrain mapping, and word coding allow the implementation of the MADCAMP system with an extremely small demand on computer capacity. The prototype system was developed using less than 40,000 words of computer random access memory. Even this relatively crude

system could then be implemented on a modern microcomputer the size of an electric typewriter. The transporting of such a system would be a minor task which would allow deployment to any forward location even in a wartime environment.

3. Because of the small size and relatively low cost of computers capable of implementing the MADCAMP system, maintenance would become nearly non-existent. In a wartime environment it is conceivable that no maintenance would be accomplished on the system. Instead, malfunctioning equipment would simply be discarded. At most, maintenance would involve replacement of only complete major components, perhaps, the entire output unit or central processor unit.

4. Since the MADCAMP system considers multiple factors when selecting an appropriate flight path, a low level of air-defense location information does not render the system useless. In fact, the MADCAMP system will provide the best flight path while considering any degree of air-defense location intelligence available. The use of no-go-zones allows the operator to include in the flight path generation process intelligence or mission essential information other than air-defense locations. This added planning flexibility would be invaluable in a dynamic environment, such as, the BAI environment.

5. Intelligence information is provided to the MADCAMP system as an input file. Therefore, updating of this information can be accomplished on a near real time basis eliminating the requirement for extensive intelligence briefings prior to initiating the mission planning process. The system output could easily be designed to provide completed form 70's and even enroute maps with potential air-defenses located. Ultimately, the aircrews would not even take part in the mission planning process and could be on airborne alert with route and target information data linked to them.

The culminationation of these individual considerations is that the multi-attribute decision approach to a computer aided mission planning system (MADCAMP) is a feasible method of significantly increasing the mission planning responsiveness and overall mission effectiveness of battlefield air interdiction.

5 Recommendations

Having completed this initial study of feasibility of a MADCAMP system in the BAI environment, the authors offer the following recommendations for further development of the system.

1. The effects of variation in the weightings and relative values used in the scoring function were not investigated to a significant degree. Only a rudimentary sensitivity analysis was performed. Therefore, a more complete sensitivity analysis of all the factors used in the scoring function should be accomplished. Information derived in this manner would most certainly result in a better simulation of the mission planner's preference structure. The better the scoring function simulates this structure the more reliable the results would become and the more acceptable the system would be to the potential users.
2. The prototype MADCAMP system did not consider the effects of electronic countermeasures or weather in its scoring function. The influence these factors have on the BAI mission planning process is not easily assessed. Both of these factors should be investigated and a determination made as to whether their effect should be included in the scoring function.

3. The elevation data used in the study was accumulated by hand and is therefore approximate. A procedure must be developed which would permit the use of elevation data available from the Defense Mapping Agency. Such a procedure would require transforming of the data into a format compatible with the selective terrain mapping scheme developed for the MADCAMP system.

4. The input/output of the prototype MADCAMP system would not be adequate for use in an operational environment. The system should be capable of using longitude and latitude coordinates (instead of cartesian coordinates) for locating of the FEBA entry point, IP, no-go-zones, and target. In addition, the output should provide information compatible with the AF Form 70 requirements. These could both be accomplished using relatively minor sub-programs. It would speed the interactive process if the system could be developed to use a light sensitive output display. In this manner, a light pen or cursor could be used by the operator to designate turnpoints.

5. Although the aircrews who produced the test missions for the study were all highly experienced tactical pilots, the environment in which the mission planning task was performed was far from that expected in wartime. It would be useful to expand the testing of the MADCAMP system to more closely simulate this

environment. One method of doing this would be to couple the collection of test missions with the conduct of operational readiness inspections (ORI's) in the European theatre. The same basic techniques could be used to test the system, but the increased realism and number of test missions would result in greater insight into the overall feasibility of the approach.

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Appendix A: Elicitation of Scoring Function Data

A total of ten aircrew members with experience in tactical aircraft were interviewed during the elicitation of the scoring function data. Aircrew experience levels are listed in Table A-1.

The aircrew members were asked to score four sub-goals (terrain features, cultural features, enemy air-defenses, and total exposure) as to their relative importance in the mission planning process. The sub-goals were scored on a scale from one to ten, with a value of ten assigned to the most important sub-goal and the remaining assigned values in relation to the most important sub-goal. The scores assigned by each aircrew member were then normalized and averaged for each sub-goal to determine the mean ($\bar{x}$) and standard deviation (s) of the normalized scores.

This process was then repeated for each category within the main sub-goals of terrain features, cultural features, and enemy defenses. The means of the normalized scores for the categories within each sub-goal were then placed on a scale of Ø to Ø.99. The category with the largest mean was assigned a value of Ø.99 and the remaining categories assigned values directly proportional to the ratio of their mean to the largest mean. These relative values were then used in the scoring function for each of the categories.

TABLE A-1

Aircrew Experience:
Aircrews Completing Questionnaire

AIRCREW	TIME TAC ACFT	TOTAL TIME
1	810	3000
2	1980	2800
3	1900	2800
4	1975	3300
5	1000	1350
6	2000	2250
7	2050	3200
8	1800	2050
9	2050	2600
10	1950	2200
AVERAGE	1751	2555

The weights for each of the main sub-goals in the linear model were set at Ø.25 for the first order evaluation of MADCAMP. This varies slightly from the weights determined by the elicitation process; however, for the following reasons, the authors believe the equal weighting to be appropriate.

1. The means of the normalized weights are approximately equal and each has a relatively large standard deviation.
2. During internal validation of MADCAMP, the weight for each of the sub-goals was increased and then decreased an amount equal to one standard deviation while holding the weights for the remaining sub-goals constant. A flight path, using the same entry point and destination coordinates, was generated for each new set of weights. There was essentially no change in the MADCAMP generated flight path as a result of the change in sub-goal weighting.

The normalized weightings for the sub-goals and the relative values for the attribute categories are presented in Table A-2.

A sample questionnaire follows:

TABLE A-2

Scoring Data

AIRCREW MEMBER / ATTRIBUTE	1	2	3	4	5	6	7	8	9	10	$\bar{x}$	s	$\hat{x}$
TERRAIN	.22	.19	.26	.21	.30	.32	.31	.39	.30	.23	.27	.06	
CULTURAL	.25	.15	.22	.11	.33	.21	.28	.44	.33	.19	.25	.10	
ENEMY DEFENSE	.27	.40	.35	.32	.13	.36	.07	.13	.20	.26	.25	.11	
TOTAL EXPOSURE	.26	.27	.17	.36	.23	.11	.35	.04	.17	.32	.23	.11	
RELATIVE VALUES FOR ATTRIBUTE CATEGORIES													
TERRAIN													
1	.26	.20	.21	.24	.21	.13	.16	.19	.22	.14	.20	.04	.69
2	.29	.30	.29	.29	.29	.27	.26	.26	.30	.23	.28	.02	.99
3	.14	.15	.15	.12	.09	.23	.23	.13	.16	.20	.16	.05	.57
4	.16	.27	.26	.25	.27	.33	.25	.25	.28	.28	.26	.04	.93
5	.06	.08	.06	.03	.30	.00	.03	.00	.00	.06	.04	.03	.12
6	.09	.00	.03	.06	.12	.04	.07	.05	.04	.09	.06	.03	.25
CULTURAL FEATURES													
1	.17	.04	.08	.06	.07	.06	.06	.03	.02	.09	.07	.04	.22
2	.18	.12	.16	.16	.12	.15	.16	.14	.06	.17	.13	.03	.42
3	.04	.00	.02	.03	.03	.00	.00	.00	.00	.03	.02	.02	.06
4	.20	.33	.25	.27	.29	.27	.31	.21	.31	.23	.28	.04	.88
5	.19	.17	.19	.18	.18	.22	.19	.28	.23	.20	.20	.03	.66
6	.22	.34	.31	.30	.31	.30	.28	.34	.38	.28	.31	.04	.99
ENEMY AIR-DEFENSES													
1	.24	.35	.31	.26	.27	.24	.27	.26	.21	.24	.27	.04	.82
2	.27	.38	.38	.29	.32	.28	.31	.32	.42	.26	.32	.05	.99
3	.19	.19	.19	.20	.13	.18	.04	.04	.12	.32	.15	.06	.45
4	.30	.08	.12	.25	.28	.31	.38	.38	.25	.29	.27	.10	.82

Questionnaire

QUESTIONNAIRE TO DETERMINE SUBJECTIVE WEIGHTINGS FOR TACTICAL MISSION PLANNING FACTORS

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Thesis Data

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In planning low-level tactical missions, the mission planner goes through a very careful process of mentally weighting all the possible factors that could affect the mission. Four major areas of concern in selecting a route of flight are making the best tactical use of terrain, avoiding lines of communication (LOC), populated areas, and military installations, avoiding areas of known or suspected enemy air defenses, and minimizing total time in the threat area.

The mission planner will select, if possible, a route that maximizes the tactical value of the terrain and therefore, minimizes his exposure to enemy threats. He will select terrain areas that offer the least probability of detection and the greatest amount of flexibility in destroying a tracking solution if detected.

When considering cultural features, it is important to avoid them to the maximum extent possible. Major cities, LOC's, and military installations tend to be more heavily defended. If for no other reason, over flight of these areas greatly reduces the element of surprise and increases the probability of detection by passive means such as visual sighting by the local populace.

The third area of concern is that of minimizing total exposure to the enemy. The less time spent behind enemy lines, the greater the chances of survival. Given a uniform distribution of terrain, cultural features and threat, the optimum route would be a straight line to the target area.

The final area that is to be considered is the threat. Again, total avoidance is preferred. If this is not possible, the mission planner should plan the route to avoid those threats that have the highest probability of effecting a kill.

During the planning process, the mission planner subjectively weights each factor in his mind and lays out a route that maximizes the probability of survival. In the attached questionnaire, we are eliciting your opinion as to the relative importance of each of these factors in the mission planning process.

To complete the questionnaire, weight each category as to its importance in the mission planning process; "How important is terrain when compared to cultural features, total exposure, and enemy defense systems?" Once this has been accomplished, repeat the process for the subareas within the major categories of terrain, cultural features, and threats. To accomplish the weighting process, rank order the major categories according to importance and rate each category on a scale of zero to ten. Assign a value of ten to the most important category and rate the remaining categories as they compare in importance to that most important category. Repeat the process for the subareas within each major category.

APPENDIX A: Tactical Considerations

In mission planning it is important to take maximum advantage of available terrain and at the same time to minimize total exposure and avoid cultural features and enemy threats.

Rate the four categories on a scale from zero to ten according to their relative importance to the mission planning process. Rate the most important category a 1Ø and the remaining categories as they compare to that most important category. Place a 1, 2, 3, or 4 at the appropriate position on the scale and enter a numerical scale value in the space provided by each category.

TACTICAL
CONSIDERATIONS

TERRAIN FEATURES	CULTURAL FEATURES	ENEMY DEFENSE SYSTEMS	TOTAL EXPOSURE

0	1	2	3	4	5	6	7	8	9	1Ø

TERRAIN FEATURES	_______	CULTURAL FEATURES	_______
ENEMY DEFENSES	_______	TOTAL EXPOSURE	_______

APPENDIX B: Cultural Features

In low-level penetration tactics, it is highly desirable to avoid LOC's, military installations and population centers. Given the following areas depicting varing degrees of cultural development (see pages B-2 and B-3), rank order each area according to potential threat to low-level penetration. Rate the cultural areas on a scale from Ø to 1Ø according to their potential threat. Rate the area that you feel has the highest potential threat a 1Ø and then rate the remaining areas as they compare to that area of most importance. Place the numerical designator for each area on the scale provided according to potential and enter a numerical value in the space provided by each type area.

0 1 2 3 4 5 6 7 8 9 1Ø

Area 1 _____	Area 2 _____	Area 3 _____
Area 4 _____	Area 5 _____	Area 6 _____

Cultural Feature No. 1

Areas of light population, rural farming communities, no industrial centers.

Cultural Feature No. 2

Minor population centers, small industrial centers.

Cultural Feature No. 3

Areas of essentially zero permanent population, deserts, swamps.

Cultural Feature No. 4

Major population centers, industrial complexes, seaports.

Cultural Feature No. 5

Major LOC's (major highways, major railways, water ways by themselves or in any combination).

Cultural Feature No. 6

Military Installations.

At what range from each particular type of cultural area does the potential threat go to zero? That is, at what range would you no longer consider it a factor in the mission planning problem.

Feature 1 ________NM

Feature 2 ________NM

Feature 3 ________NM

Feature 4 ________NM

Feature 5 ________NM

Feature 6 ________NM

APPENDIX C: Terrain

Evaluate each of the terrain areas depicted, rank order and rate them on a scale from Ø to 1Ø according to their tactical value. Rate the area that has the highest tactical value a 1Ø and the other areas according to their tactical value as compared to that most significant terrain area. Tactical value is defined as the flexibility the terrain area offers an aircrew in avoiding detection and destroying a tracking solution by enemy air defense systems. The defense systems may be radar, IR, or optically guided.

Flight Scenario

1. Average flight altitude, 200 feet AGL.

2. Flight direction is left to right across the terrain area. The flight path may be varied slightly to make maximum use of terrain features. The main object is to traverse the area as quickly as possible.

3. Consider each area to contain equal numbers of highly mobile enemy air defense systems.

4. Disregard all cultural features within each of the terrain areas depicted.

Place the numerical designator for each area on the scale provided according to its tactical value and enter a numerical value in the space provided by each type area.

0 1 2 3 4 5 6 7 8 9 1Ø

Area 1_____	Area 2_____	Area 3_____
Area 4_____	Area 5_____	Area 6_____

Terrain Area 1

Crisscrossing mountain valleys, requiring continuous altitude changes.

Terrain Area 2

Paraller ridge lines with greater than 3000 ft. vertical development.

Terrain Area 3

Rolling terrain, little vertical development, no definite ridge lines.

Terrain Area 4

Parallel ridge lines with 1000 ft to 3000 ft vertical development.

Terrain Area 5

Flat terrain with little to no vertical development.

Terrain Area 6

Isolated ridge line with greater than 1000 ft vertical development.

APPENDIX D: Threat

Four hypothetical enemy air defense systems are presented for evaluation. The system descriptions and capabilities are listed in Table D-1. All systems are highly mobile. Inside the lethal radius, the probability of kill (PK) is uniformly distributed over the entire area. Outside the lethal radius the PK is zero.

Based on the system description and capabilities, rate each system according to its threat to mission success. Rank order the threats according to their capability and then on a scale from Ø to 1Ø. A value of ten will be assigned to the system you believe to be the greatest threat. Rate the remaining threats as they compare to that most important threat. Place the threat numerical designator at the appropriate position on the scale below and enter the numerical value of the rating on the space provided by each type threat.

TABLE D-1

Threat Description and capabilities

SAM NUMERICAL DESIGNATOR	MISSILE SIZE	LOW ALTITUDE CAPABILITY	MISSILE GUIDANCE	MAX G's REQUIRED TO DEFEAT
1	Medium	≤ 100 ft	Radar/optical	6.5
2	Small	≤ 100 ft	Radar/optical	GT6.5
3	Small	≤ 100 ft	IR/tail only	5.0

AAA DESIGNATOR	RATE OF FIRE RND/MIN	ALTITUDE CAPABILITY	GUIDANCE	MAX G's TO DEFEAT
4	3500-4500	Sur-17000'	Radar/ optical	Constant Maneuvering

Ø 1 2 3 4 5 6 7 8 9 1Ø

Threat 1_____ Threat 2_____ Threat 3_____ Threat 4_____

Given the areas of overlapping threat coverage depicted on pages D-2 thru D-8, select the route that you would prefer in crossing each threat area.

APPENDIX E: General Questions

1. In your opinion, do the terrain areas presented adequately represent the types of terrain features that you would expect to encounter in a tactical mission planning problem? If not, what other representative terrain features would you include?

REMARKS:

2. In your opinion, do the cultural patterns presented adequately represent the types of cultural buildups that you would expect to encounter in a tactical mission planning problem? If not, what other representative cultural features would you include?

REMARKS:

Appendix B: Fortran Source Code

```
C        FORTRAN CODE FOR IMPLEMENTING A PROTOTYPE
C         MULTI-ATTRIBUTE DECISION COMPUTER AIDED
C         MISSION PLANNING SYSTEM
C
C*********************************************************************
       PROGRAM THESIS 1 (INPUT, TAPE 6, TAPE 7, OUTPUT)
       INTEGER XE,YE,XD,YD,X1,X2,Y1,Y2,X,Y,FM,TR
       DIMENSION FM(70,50,2),TR(10,10,49),TH(50,4)
C
C*********************************************************************
C
C         ENTER MISSION DATA
C
C*********************************************************************
1      PRINT *,"     ","ENSURE PROPER TERRAIN MAP IS IN TAPE 6"
       PRINT *,"     ","ENSURE PROPER THREAT LIST IS IN TAPE 7 "
2      PRINT *,"     ","ENTER X AND Y COORDINATES FOR ENTRY POINT - "
       READ *,XE,YE
       PRINT *,"     ","ENTER X AND Y COORDINATES FOR DESTINATION - "
       READ *,XD,YD
       PRINT *,"     ","ENTER AIRCRAFT USEABLE RANGE - "
       READ *,IR
       CR=FLOAT(IR)
C
C*********************************************************************
C
C         DIMENSION THE FLIGHT ARRAY
C
C*********************************************************************
       X1 =XE-1
       X2 =XD+1
       IF(YD.LT.YE) GO TO 10
       Y1 =YE-15
       Y2= YD+15
       GO TO 20
10     Y1= YD-15
       Y2= YE+15
20     IDY = Y2-Y1
       IDX = X2-X1
       IF(IDY.LE.50) GO TO 23
       Y1= Y1+10
```

```
      Y2= Y2-10
      IDY= Y2-Y1
23    IF((Y1.LE.10).OR.(Y2.GE.109)) GO TO 24
      IF((X1.LE.10).OR.(X2.GE.109)) GO TO 24
      IF(IDY.LE.50) GO TO 25
24    PRINT *,"     ","PICK A NEW SET OF COORDINATES OR MAP."
      GO TO 2
25    READ (6,*)N
      CALL DYPROG(XE,YE,XD,YD,X1,Y1,X2,Y2,CR,IDX,IDY,RET,N,FM,TR)
      PRINT *,"     "," DO YOU WISH TO ADD ANY NO-GO-ZONES? YES = 1 -  "
      READ *,N
      IF(N.EQ.1) GO TO 25
      PRINT *,"     ","DO YOU WISH TO ENTER A NEW FLIGHT?YES = 1 - "
      READ *,N
      IF(N.EQ.1) GO TO 1
      STOP
      END
      SUBROUTINE DYPROG(XE,YE,XD,YD,X1,Y1,X2,Y2,CR,IDX,IDY,RET,N,FM,TR)
      INTEGER FM,TP,X,Y,XTH,YTH,LR,ETH,DY,XD,YD,XE,YE ,X1,Y1,X2,Y2,TH
      DIMENSION FM(IDX,IDY,2),TH(50,4),VA(5),IDA(5),TR(10,10,N),
     *IVA(5),INZ(5,3),CUL(10,3),ILOG(10),NR(10,5)
      DATA TH/200*0./,NR/50*0/
      INDEX=0
      IND=1
C
C*************************************************************************
C
C        READ TERRAIN AND THREAT FILES
C
C*************************************************************************
      DO 5 J=1,IDY
      DO 5 K=1,IDX
        FM(K,J,1)=20000
        FM(K,J,2)=0
5     CONTINUE
      FM(XD-X1,YD-Y1,1)=0
      READ (6,*)(((TR(I,J,K),I=1,10),J=1,10),K=1,N)
      READ(6,*)NC
      READ(6,*)((CUL(I,J),J=1,3),I=1,NC)
      READ(6,*) KR
      READ(6,*)((NR(I,J),J=1,5),I=1,KR)
      READ (7,*)NT
      IF(NT.EQ.0) GO TO 11
      READ (7,*)((TH(J,I),I=1,4),J=1,NT)
```

```
C************************************************************************
C
C         ENTER NO-GO-ZONES
C
C************************************************************************
      PRINT *,"     ","ENTER NUMBER OF NO-GO-ZONES -  "
      READ *,NNZ
      IF(NNZ.EQ.0) GO TO 11
      DO 9 I=1,NNZ
        PRINT *,"     ","ENTER X AND Y COORDINATES AND RADIUS - "
        READ *,INZ(I,1),INZ(I,2),INZ(I,3)
9     CONTINUE
C
C************************************************************************
C
C         INITIATE EVALUATION PROCESS - XD,YD-1
C
C************************************************************************
11    IIDY= -1
12    Y = YD+IIDY
      X = XD
C
C************************************************************************
C
C         TEST FEASIBILITY OF THE POINT
C
C************************************************************************
15    IF(Y.EQ.Y2) GO TO 120
18    IF((Y.LE.(Y1+1)).OR.(Y.GE.Y2)) GO TO 110
      IF(X.LT.X1) GO TO 110
      TD1=SQRT(FLOAT((XD-X)**2+(YD-Y)**2))
     *+SQRT(FLOAT((XE-X)**2+(YE-Y)**2))
      IF(TD1.GT.CR) GO TO 110
      VE = 0.
C
C************************************************************************
C
C         DETERMINE TERRAIN VALUE (VT)
C
C************************************************************************
      IX=X/10
      IY=Y/10
      ICODE=TR(IX,IY,1)
      ICAT =ICODE/100
      ICATP=ICAT
      IVT =ICODE-ICAT*100
      VT =IVT/100.
      IF(ICAT.EQ.2) GO TO 25
      IXS=X-IX*10+1
      IYS=Y-IY*10+1
```

```
      GO TO 26
25    IXS=IX
      IYS=IY
26    ICODE=TR(IXS,IYS,ICAT)
      IEPR =ICODE/100
      IVTA=  ICODE-IEPR*100
      VTA =IVTA/100.
      VT=VT+VTA
      VC=0.
C
C************************************************************************
C
C        TEST FOR NO-GO-ZONE
C
C************************************************************************
      IF(NNZ.EQ.0) GO TO 19
      DO 19 I=1,NNZ
         ZD=SQRT(FLOAT((INZ(I,1)-X)**2+(INZ(I,2)-Y)**2))
         ZR=FLOAT(INZ(I,3))
        IF(ZD.GT.ZR) GO TO 19
        VPT=2.
        GO TO 61
19    CONTINUE
C
C************************************************************************
C
C        DETERMINE VALUE FOR POINT CULTURAL FEATURES
C
C************************************************************************
      DO 20 I=1,NC
        RC=((CUL(I,1)-X)**2+(CUL(I,2)-Y)**2)**.5
        IF(RC.GT.20) GO TO 20
          VC=(1-RC/20.)*CUL(I,3)/100.
20    CONTINUE
C
C************************************************************************
C
C        DETERMINE VALUE FOR LINEAR CULTURAL FEATURES
C
C************************************************************************
      RPMIN=10.
      DO 21 I=1,KR
        DX=X-NR(I,1)
        DY=Y-NR(I,2)
        R=SQRT(DX**2+DY**2)
        IF(R.EQ.0) GO TO 21
        COS=(NR(I,3)*DX+NR(I,4)*DY)/(NR(I,5)*R)
      IF(COS.LT.0.) GO TO 21
        IF(COS**2.GT.1.) COS=1.
        RP=R*SQRT(1-COS**2)
```

```
      IF(RP.GE.10.) GO TO 21
      IF((RP**2+R**2).GT.FLOAT(NR(I,5)**2)) GO TO 21
      RPMIN=AMIN1(RP,RPMIN)
21    CONTINUE
      VR=.66*(1-RPMIN/10.)
C
C**********************************************************************
C
C        DETERMINE VALUE FOR MOST IMPORTANT CULTURAL FEATURE (VC)
C
C**********************************************************************
      IF(VR.GT.VC) VC=VR
C
C**********************************************************************
C
C        DETERMINE VALUE FOR THREAT EXPOSURE (VE)
C
C**********************************************************************
22    DO 60 I=1,NT
        XTH = TH(I,1)
        YTH = TH(I,2)
        RT= SQRT(FLOAT((XTH-X)**2+(YTH-Y)**2))
        LR =TH(I,3)
        IF(RT.GT.LR) GO TO 60
C
C**********************************************************************
C
C        TEST FOR TERRAIN MASKING
C
C**********************************************************************
        IXT=XTH/10
        IYT=YTH/10
        ICODT=TR(IXT,IYT,1)/100
        IF(ICODT.EQ.2) GO TO 23
        IXTS=XTH-IXT*10+1
        IYTS=YTH-IYT*10+1
        GO TO 24
23      IXTS=IXT
        IYTS=IYT
24      ETH=TR(IXTS,IYTS,ICODT)/100+1
        IEP=IEPR
        IF((ICATP.GT.2).OR.(ICODT.GT.2)) GO TO 29
        IF(IEPR.GT.ETH) ETH=IEP
        IF(ETH.GE.IEPR) IEP=ETH
29      IF((X.EQ.XTH).AND.(Y.EQ.YTH)) GO TO 57
        IF(ABS(FLOAT(XTH-X)).LT.ABS(FLOAT(YTH-Y))) GO TO 39
        MR =FLOAT(Y-YTH)/FLOAT(X-XTH)
        MA =FLOAT(IEP-ETH+2)/ABS(FLOAT(X-XTH))
        N =ABS(FLOAT(X-XTH))
        K =(X-XTH)/N
```

```
         DO 37 J=1,N
           IYR =MR*J*K+YTH
           IX =(XTH+J*K)/10
           IY =IYR/10
30         ICAT=TR(IX,IY,1)/100
           IF(ICAT.EQ.2) GO TO 34
           IXS =(XTH+N*K)-IX*10+1
           IYS =IYR-IY*10+1
           GO TO 36
34         IXS=IX
           IYS=IY
36         ICODE =TR(IXS,IYS,ICAT)
           IEO=ICODE/100
           IEL =J*MA+ETH
           IF(IEO.GT.IEL) GO TO 60
37       CONTINUE
         VE=VE+TH(I,4)/100.
         GO TO 60
39       MA =FLOAT(IEP-ETH+2)/ABS(FLOAT(Y-YTH))
         MR= FLOAT(X-XTH)/FLOAT(Y-YTH)
         L =ABS(FLOAT(Y-YTH))
         K =(Y-YTH)/L
         DO 55 J=1,L
           IXR=MR*J*K+XTH
           IX=IXR/10
           IY=(YTH+J*K)/10
           ICAT =TR(IX,IY,1)/100
           IF(ICAT.EQ.2) GO TO 40
           IXS =X-IX*10+1
           IYS =(YTH+J*K)-IY*10+1
           GO TO 50
40         IXS =IX
           IYS =IY
50         ICODE =TR(IXS,IYS,ICAT)
           IEO=ICODE/100
           IEL =J*MA+ETH
           IF(IEO.GT.IEL) GO TO 60
55       CONTINUE
57       VE=VE=TH(I,4)/100.
60     CONTINUE
C
C***************************************************************************
C
C         DETERMINE OPTIMAL DIRECTION OF MOVE, ACCUMULATED
C         VALUE, AND TOTAL DISTANCE FOR THE POINT
C
C***************************************************************************
       VPT=VE*.25-VT*.25+VC*.25+.25
61     IJ= X-X1
       IK= Y-Y1
```

```
      VA(1) =FM(IJ,IK+1,1)/100.+VPT
      VA(2) =FM(IJ+1,IK+1,1)/100.+1.4*VPT
      VA(3) =FM(IJ+1,IK,1)/100.+VPT
      VA(4) =FM(IJ+1,IK-1,1)/100.+1.4*VPT
      VA(5) =FM(IJ,IK-1,1)/100.+VPT
      IDA(1) =FM(IJ,IK+1,2)/10+10
      IDA(2) =FM(IJ+1,IK+1,2)/10+14
      IDA(3) =FM(IJ+1,IK,2)/10+10
      IDA(4) =FM(IJ+1,IK-1,2)/10+14
      IDA(5) =FM(IJ,IK-1,2)/10+10
      VAMIN =VA(1)
      DO 70 J=2,5
        VAMIN =AMIN1(VAMIN,VA(J))
70    CONTINUE
      DO 80 J=1,5
        IVA(J) =0
        IF(VA(J).EQ.VAMIN) IVA(J) =1
80    CONTINUE
      IDAMIN =10000
      DO 90 J=1,5
        IF(IVA(J).EQ.0) IDA(J)=1000
        IDAMIN =MIN0(IDAMIN,IDA(J))
90    CONTINUE
      DO 100 J=1,5
        IF(IDA(J).EQ.IDAMIN) ICODE =J
100   CONTINUE
      RA=SQRT(FLOAT((XE-X)**2+(YE-Y)**2))+IDA(ICODE)/10.
      IF(RA.GT.CR) GO TO 101
      FM(IJ,IK,2) =IDA(ICODE)*10+ICODE
      FM(IJ,IK,1) =IFIX(VA(ICODE)*100.)
      IF((X.EQ.XE).AND.(Y.EQ.YE)) GO TO 150
      GO TO 110
101   FM(IJ,IK,2) =20000
      FM(IJ,IK,1) =5000
110   IF(Y.GE.YD) GO TO 130
C
C*******************************************************************
C
C          DETERMINE NEXT POINT TO BE EVALUATED
C
C*******************************************************************
      Y =Y+1
      X =X-1
      GO TO 15
120   Y =YD-IIDY
      X =XD
      GO TO 18
130   Y =Y-1
      X =X-1
      IF(Y.LT.YD) GO TO 140
```

```
      GO TO 12
140   IIDY =IIDY-1
      GO TO 12
C
C***********************************************************************
C
C        PRINT RECOMMENDED FLIGHT PATH
C
C***********************************************************************
150   Y =YE-Y1
      X =1
      ILOG(IND)=FM(X,Y,1)
      IF(INDEX.GT.0) GO TO 250
      PRINT*,"     ACCUMULATED RISK = ",FM(X,Y,1)
      DO 155 I=1,IDY
      DO 155 J=1,IDX
        FM(J,I,1)=" "
155   CONTINUE
160   FM(X,Y,1)="X"
      IF((X.EQ.(XD-X1)).AND.(Y.EQ.(YD-Y1))) GO TO 200
      ICODE =FM(X,Y,2)
      ICODE = ICODE-(ICODE/10)*10
      GO TO (165,170,175,180,185)ICODE
165   Y =Y+1
      GO TO 160
170   Y =Y+1
      X =X+1
      GO TO 160
175   X =X+1
      GO TO 160
180   X =X+1
      Y =Y-1
      GO TO 160
185   Y =Y-1
      GO TO 160
200   PRINT *,"     ","  COORDINATES OF FEBA ENTRY = ",XE,YE
      DO 220 I=1,IDY
        K= Y2+1-I
        L=IDY+1-I
        PRINT 300,K,(FM(J,L,1),J=1,IDX)
220   CONTINUE
      PRINT 530,("I",I=XE,XD)
      PRINT 400,(I,I=XE,XD,5)
C
C***********************************************************************
C
C        ENTER PROPOSED FLIGHT SEGMENTS IF DESIRED
C
C***********************************************************************
230   PRINT*,"     ENTER NUMBER OF LEGS - "
```

```
      READ*,INDEX
      IND=0
250   IF(IND.EQ.INDEX) GO TO 254
      PRINT*,"     ENTER STARTING COORDINATES-X AND Y -"
      READ*,XE,YE
      PRINT*,"     ENTER ENDING COORDINATES-X AND Y -"
      READ*,XD,YD
      CR=(SQRT(FLOAT((XD-XE)**2+(YD-YE)**2)))*1.1
      IF(YD.GE.YE) GO TO 251
      Y1=YD-2
      Y2=YE+2
      GO TO 252
251   Y1=YE-2
      Y2=YD+2
252   X1=XE-1
      X2=XD+1
      IDX=X2-X1
      IDY=Y2-Y1
      DO 253 J=1,IDY
      DO 253 K=1,IDX
        FM(K,J,1)=2000
        FM(K,J,2)=0
253   CONTINUE
      FM(XD-X1,YD-Y1,1)=0
      IND=IND+1
      GO TO 11
254   DO 255 I=1,INDEX
        PRINT*,"     LEG - ",I,"   RISK = ",ILOG(I)
255   CONTINUE
      PRINT*,"     DO YOU WISH TO ENTER A NEW FLIGHT PATH? -"
      READ*,N
      IF(N.EQ.1) GO TO 230
300   FORMAT(5X,I3,70A1)
400   FORMAT(7X,14(I3,2X))
500   FORMAT(8X,70A1)
      REWIND6
      REWIND7
      RET=1.0
      RETURN
      END
```

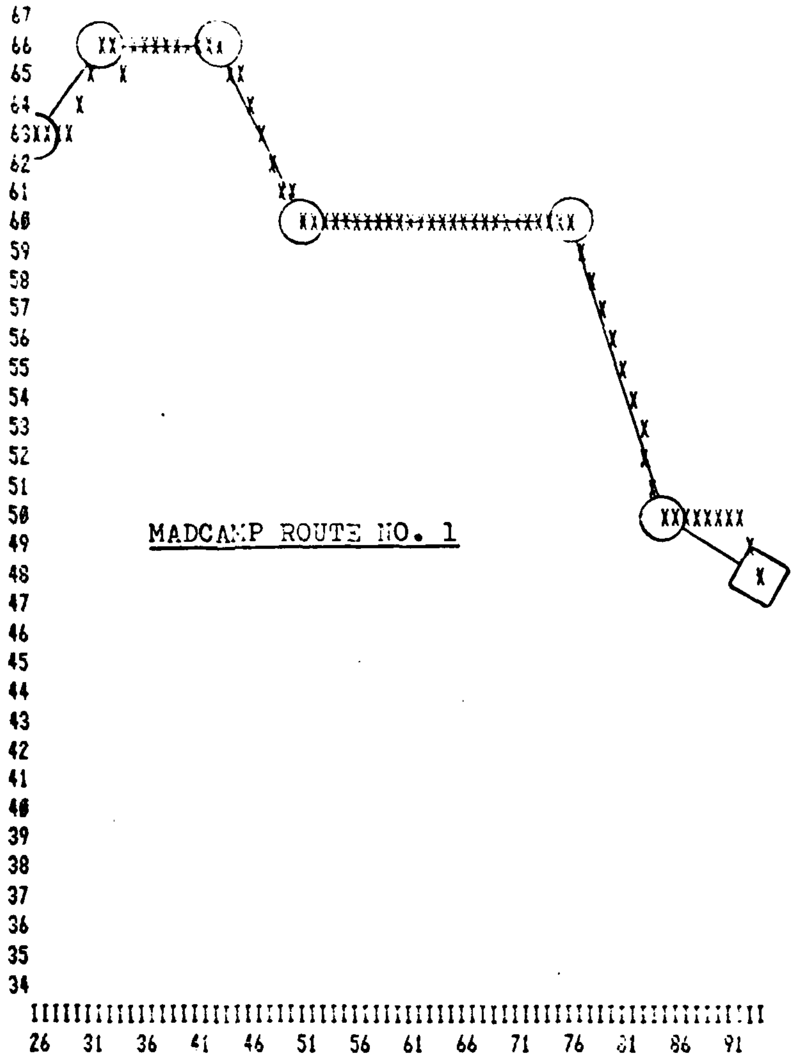
Appendix C: Source Routes

The MADCAMP routes for targets one through five are presented on pages 135 through 139. The actual flight path evaluated by the tactical aircrew members has been added indicating turn points, IP, and ground track.

The routes, controlled entry points, route length, and turn point coordinates for all routes are presented by source in Tables C-1 through C-6.

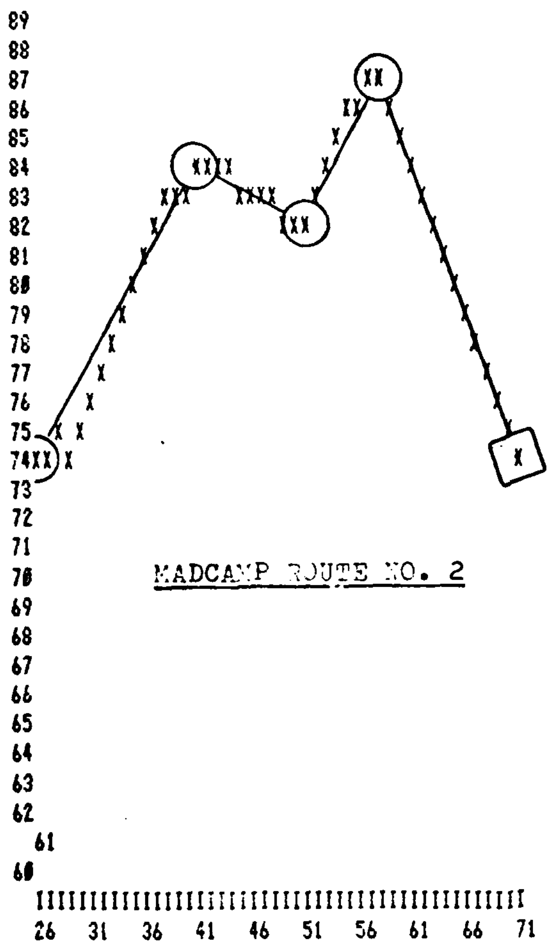
Experience levels of the aircrew members preparing the source routes are provided in Table C-7.

```
ENSURE PROPER [illegible] IS IN TAPE 6
 ENSURE PROPER THREAT LIST IS IN TAPE 7
 ENTER X AND Y COORDINATES FOR ENTRY POINT -26 63
ENTER X AND Y COORDINATES FOR DESTINATION - 94 48
ENTER AIRCRAFT USEABLE RANGE -  148
ENTER NUMBER OF NO-GO-ZONES -     1
ENTER X AND Y COORDINATES AND RADIUS -     95 51 2
ACCUMULATED RISK = 1637
   COORDINATES OF FEBA ENTRY = 26 63
```



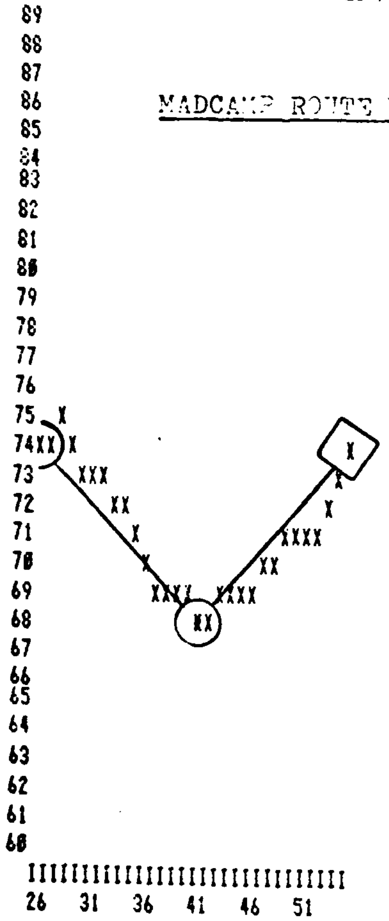
MADCAMP ROUTE NO. 1

```
ENSURE PROPER TERRAIN MAP IS IN TAPE 6
 ENSURE PROPER THREAT LIST IS IN TAPE 7
 ENTER X AND Y COORDINATES FOR ENTRY POINT -26 74
ENTER X AND Y COORDINATES FOR DESTINATION - 71 74
ENTER AIRCRAFT USEABLE RANGE -  90
ENTER NUMBER OF NO-GO-ZONES -    1
ENTER X AND Y COORDINATES AND RADIUS -    71 72 2
ACCUMULATED RISK = 952
   COORDINATES OF FEBA ENTRY = 26 74
```

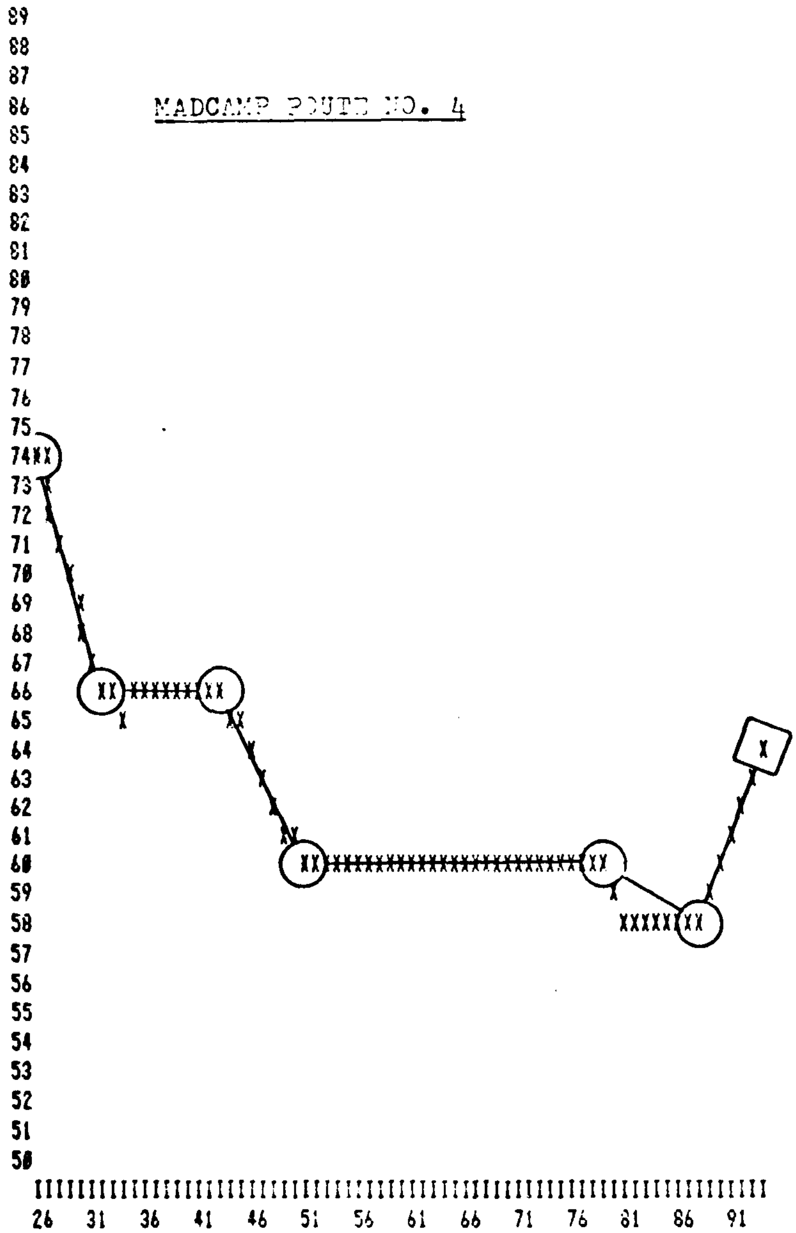


MADCAMP ROUTE NO. 2

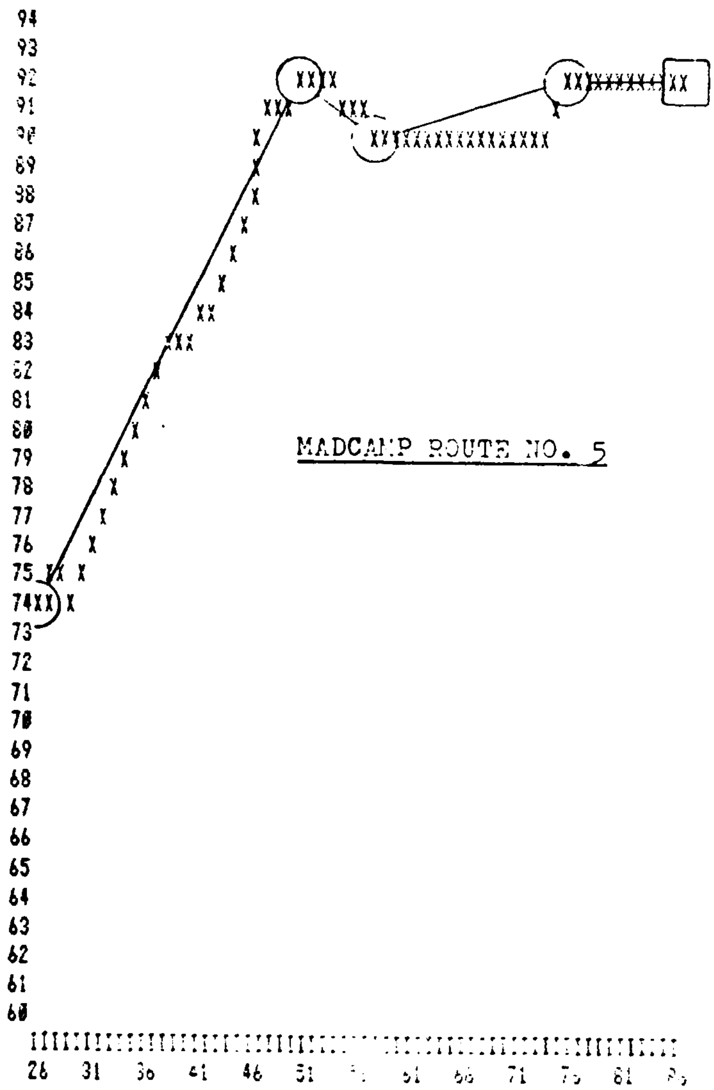
```
ENSURE PROPER TERRAIN MAP IS IN TAPE 6
 ENSURE PROPER THREAT LIST IS IN TAPE 7
 ENTER X AND Y COORDINATES FOR ENTRY POINT -26 74
ENTER X AND Y COORDINATES FOR DESTINATION - 55 74
ENTER AIRCRAFT USEABLE RANGE -  58
ENTER NUMBER OF NO-GO-ZONES -     1
ENTER X AND Y COORDINATES AND RADIUS -    52 74 2
ACCUMULATED RISK = [illegible]
   COORDINATES OF FEBA ENTRY = 26 74
```



```
ENSURE PROPER TERRAIN MAP IS IN TAPE 6
 ENSURE PROPER THREAT LIST IS IN TAPE 7
 ENTER X AND Y COORDINATES FOR ENTRY POINT -26 74
ENTER X AND Y COORDINATES FOR DESTINATION - 94 64
ENTER AIRCRAFT USEABLE RANGE -   137
ENTER NUMBER OF NO-GO-ZONES -      1
ENTER X AND Y COORDINATES AND RADIUS -    104 65 2
ACCUMULATED RISK = 1534
   COORDINATES OF FEBA ENTRY = 26 74
```



```
ENSURE PROPER TERRAIN MAP IS IN TAPE 6
 ENSURE PROPER THREAT LIST IS IN TAPE 7
 ENTER X AND Y COORDINATES FOR ENTRY POINT -26 74
ENTER X AND Y COORDINATES FOR DESTINATION - 86 92
ENTER AIRCRAFT USEABLE RANGE -   125
ENTER NUMBER OF NO-GO-ZONES -       1
ENTER X AND Y COORDINATES AND RADIUS -  88 95 2
ACCUMULATED RISK = 1150
   COORDINATES OF FEBA ENTRY = 26 74
```



MADCAMP ROUTE NO. 5

TABLE C-1

Route Source MADCAMP Turn Points

ROUTE	CONTROLLED ENTRY POINT	LENGTH	TURN POINT COORDINATES
1	4	74 nm	46-47N 121-02W
			46-50N 120-54W
			46-50N 120-38W
			46-44N 120-26N
			46-44N 119-50W
			46-34N 119-37W
			46-32N 119-23W
2	5	54 nm	46-58N 121-02W
			47-08N 120-41W
			47-06N 120-27W
			47-11N 120-16W
			46-58N 119-57W
3	5	32 nm	46-58N 121-02W
			46-52N 120-40W
			46-58N 120-21W
4	5	75 nm	46-58N 121-02W
			46-50N 120-54W
			46-50N 120-38W
			46-44N 120-26W
			46-44N 119-45W
			46-42N 119-32W
			46-48N 119-23W
5	5	67 nm	46-58N 121-02W
			47-16N 120-28W
			47-14N 120-18W
			47-16N 119-51W
			47-16N 119-35W

TABLE C-2

Route Source No. 1 Turn Points

ROUTE	CONTROLLED ENTRY POINT	ROUTE LENGTH	TURN POINT COORDINATES
1	1	75 nm	46-10N 121-02W 46-13N 119-55W 46-32N 119-23W
2	5	59 nm	46-58N 121-02W 47-13N 120-00W 46-58N 119-57W
3	4	31 nm	46-47N 121-02W 46-58N 120-21W
4	4	78 nm	46-47N 121-02W 47-04N 119-51W 46-48N 119-22W
5	4	68 nm	46-47N 121-02W 47-04N 119-51W 47-16N 119-35W

TABLE C-3

Route Source No. 2 Turn Points

ROUTE	CONTROLLED ENTRY POINT	ROUTE LENGTH	TURN POINT COORDINATES
1	1	90 nm	46-10N 121-02W 46-09N 120-30W 46-00N 119-59W 46-24N 119-44W 46-32N 119-23W
2	5	53 nm	46-58N 121-02W 47-12N 120-41W 46-58N 119-57W
3	4	32 nm	46-47N 121-02W 46-54N 120-45W 46-58N 120-21W
4	5	83 nm	46-58N 121-02W 47-12N 120-41W 47-13N 120-04W 46-48N 119-22W
5	7	85 nm	47-18N 121-19W 47-20N 120-58W 47-29N 120-38W 47-06N 119-49W 47-16N 119-35W

TABLE C-4

Route Source No. 3 Turn Points

ROUTE	CONTROLLED ENTRY POINT	ROUTE LENGTH	TURN POINT COORDINATES
1	1	100 nm	46-10N 121-02W 46-02N 120-35W 46-09N 120-22W 45-57N 119-55W 46-28N 119-41W 46-32N 119-23W
2	7	77 nm	47-18N 121-19W 47-20N 121-05W 47-27N 120-54W 47-26N 119-51W 46-58N 119-57W
3	6	76 nm	47-09N 121-19W 47-19N 121-13W 47-20N 121-05W 47-26N 120-54W 47-01N 120-13W 46-58N 120-21W
4	3	140 nm	46-39N 121-02W 46-10N 121-02W 46-02N 120-35W 46-09N 120-22W 45-57N 119-55W 46-28N 119-41W 46-48N 119-22W
5	7	77 nm	47-19N 121-19W 47-20N 121-05W 47-27N 120-54W 47-13N 120-05W 47-16N 119-35W

TABLE C-5

Route Source No. 4 Turn Points

ROUTE	CONTROLLED ENTRY POINT	ROUTE LENGTH	TURN POINT COORDINATES
1	1	99 nm	46-10N 121-02W
			46-01N 120-33W
			46-04N 120-14W
			45-57N 119-49W
			46-27N 119-40W
			46-32N 119-23W
2	7	71 nm	47-18N 121-19W
			47-20N 121-00W
			47-28N 120-35W
			46-58N 119-57W
3	6	74 nm	47-09N 121-19W
			47-19N 121-12W
			47-20N 121-00W
			47-28N 120-35W
			47-12N 120-13W
			46-58N 120-21W
4	3	131 nm	46-39N 121-02W
			46-00N 120-42W
			46-05N 120-14W
			46-00N 119-56W
			46-34N 119-39W
			46-48N 119-22W
5	7	88 nm	47-18N 121-19W
			47-20N 121-00W
			47-28N 120-35W
			47-14N 120-17W
			47-26N 119-58W
			47-16N 119-35W

TABLE C-6

Route Source No. 5 Turn Points

ROUTE	CONTROLLED ENTRY POINT	ROUTE LENGTH	TURN POINT COORDINATES
1	1	103 nm	46-10N 121-02W 45-56N 120-42W 45-56N 119-53W 46-26N 119-45W 46-32N 119-23W
2	7	98 nm	47-18N 121-19W 47-19N 120-50W 47-33N 120-36W 47-33N 120-01W 46-58N 119-57W
3	5	42 nm	46-47N 121-02W 46-44N 120-23W 46-58N 120-21W
4	3	112 nm	46-39N 121-02W 46-11N 120-47W 46-14N 119-48W 46-26N 119-45W 46-48N 119-22W
5	7	92 nm	47-18N 121-19W 47-19N 120-50W 47-33N 120-36W 47-33N 120-01W 47-16N 119-35W

TABLE C-7

Aircrew Experience: Route Source

SOURCE	TIME TAC ACFT	TOTAL TIME
1	1561	2180
2	700	1200
3	1465	2150
4	720	900
5	1800	2000
AVERAGE	1249	1686

Appendix D: Experimental Data

The flight path rankings and scores for the scource flight paths to each target are provided on pages 148 through 152.

The experience level of the aircrew members evaluating the flight paths are provided in Table D-1.

The MADCAMP generated values for each flight path source and test mission are provided in Table D-2.

The flight path rankings using mean score and accumulated value are presented by test mission in Table D-3.

ROUTE NO. 1: RANKINGS AND SCORES

ROUTE EVALUATOR	SOURCE 1 RANK	SOURCE 1 SCORE	SOURCE 2 RANK	SOURCE 2 SCORE	SOURCE 4 RANK	SOURCE 4 SCORE	SOURCE 4 RANK	SOURCE 4 SCORE	SOURCE 5 RANK	SOURCE 5 SCORE	MADCAMP RANK	MADCAMP SCORE
1	1	10	4	6	5	2	3	8	6	2	2	9
2	6	3	3	8	5	5	4	7	2	8	1	10
3	5	7	4	8	2	9	1	10	3	9	6	5
4	3	7	1	10	2	8	5	5	4	6	6	2
5	2	8	5	1	4	1	3	4	1	10	6	1
6	5	4	2	8	1	10	3	7	4	6	6	1
7	2	8	5	6	6	5	4	6	3	8	1	10
8	5	2	2	6	4	3	3	4	6	1	1	10
9	5	3	4	5	3	7	2	8	1	10	6	1
10	5	6	3	8	4	7	1	10	6	4	2	9
11	5	5	1	10	4	6	2	8	3	7	6	4

ROUTE NO. 2: RANKINGS AND SCORES

ROUTE EVALUATOR	SOURCE 1 RANK	SOURCE 1 SCORE	SOURCE 2 RANK	SOURCE 2 SCORE	SOURCE 4 RANK	SOURCE 4 SCORE	SOURCE 4 RANK	SOURCE 4 SCORE	SOURCE 5 RANK	SOURCE 5 SCORE	MADCAMP RANK	MADCAMP SCORE
1	1	10	3	8	5	4	4	6	6	4	2	9
2	5	4	1	10	4	6	3	9	6	2	2	9
3	4	5	5	4	1	10	2	8	3	8	6	4
4	5	4	4	5	2	9	1	10	3	7	6	3
5	3	7	5	1	1	10	2	8	6	1	4	3
6	6	1	1	10	2	7	3	6	5	2	4	4
7	4	6	3	7	2	9	1	10	5	5	6	4
8	4	5	1	10	3	6	5	2	6	1	2	8
9	5	2	3	6	2	8	1	10	4	5	6	1
10	4	7	2	9	6	5	1	10	5	6	3	8
11	5	4	3	7	2	9	1	10	6	3	4	6

ROUTE NO. 3: RANKINGS AND SCORES

ROUTE EVALUATOR	SOURCE 1		SOURCE 2		SOURCE 4		SOURCE 4		SOURCE 5		MADCAMP	
	RANK	SCORE	RANK	SCORE	RANK	SCORE	RANK	SCORE	RANK	SCORE	RANK	SCORE
1	1	10	3	5	5	5	4	5	6	4	2	7
2	1	10	3	8	4	6	5	5	6	3	2	9
3	4	7	5	7	1	10	2	9	6	5	3	8
4	6	4	3	7	1	10	5	5	2	8	4	6
5	1	10	3	5	5	1	4	5	6	1	2	5
6	4	5	5	3	2	8	1	10	6	1	3	6
7	4	6	5	4	2	8	1	10	6	3	3	7
8	2	7	3	6	1	10	6	1	5	2	4	4
9	2	9	1	10	6	1	5	2	4	5	3	8
10	1	10	3	8	5	5	4	6	6	4	2	9
11	3	9	2	9	4	5	5	5	6	1	1	10

ROUTE NO. 4: RANKINGS AND SCORES

ROUTE EVALUATOR	SOURCE 1 RANK	SOURCE 1 SCORE	SOURCE 2 RANK	SOURCE 2 SCORE	SOURCE 4 RANK	SOURCE 4 SCORE	SOURCE 4 RANK	SOURCE 4 SCORE	SOURCE 5 RANK	SOURCE 5 SCORE	MADCAMP RANK	MADCAMP SCORE
1	1	10	2	9	6	1	5	1	4	7	3	9
2	1	10	2	9	4	6	5	5	6	4	3	8
3	6	5	5	7	3	8	2	9	4	7	1	10
4	1	10	5	4	2	7	4	5	3	6	6	3
5	2	6	6	1	3	6	5	1	4	5	1	10
6	5	2	2	7	4	3	3	4	6	1	1	10
7	3	8	2	8	6	3	5	4	4	5	1	10
8	2	8	1	10	4	4	5	3	6	2	3	6
9	6	1	5	2	3	7	2	8	4	5	1	10
10	4	6	3	7	2	8	1	10	6	5	5	6
11	5	4	4	6	1	10	2	9	6	3	3	8

ROUTE NO. 5: RANKINGS AND SCORES

ROUTE EVALUATOR	SOURCE 1 RANK	SOURCE 1 SCORE	SOURCE 2 RANK	SOURCE 2 SCORE	SOURCE 4 RANK	SOURCE 4 SCORE	SOURCE 4 RANK	SOURCE 4 SCORE	SOURCE 5 RANK	SOURCE 5 SCORE	MADCAMP RANK	MADCAMP SCORE
1	3	5	4	3	6	1	2	7	5	3	1	10
2	6	4	5	5	3	9	1	10	4	7	2	9
3	6	3	4	6	3	8	1	10	2	8	5	5
4	4	6	1	10	6	2	2	9	3	7	5	4
5	5	2	2	5	3	5	6	1	4	3	1	10
6	6	1	2	6	4	3	5	2	3	5	1	10
7	6	4	4	6	5	4	1	10	3	8	2	9
8	2	8	4	3	3	4	5	2	6	1	1	10
9	6	1	2	8	5	2	1	10	4	5	3	6
10	5	6	4	7	6	4	1	10	3	8	2	9
11	6	5	5	6	2	9	3	9	4	8	1	10

TABLE D-1

Aircrew Experience: Route Evaluators

AIRCREW	TIME TAC ACFT	TOTAL TIME
1	1980	2800
2	2200*	2350
3	2050	2550
4	1600	1800
5	2000	2200
6	1900	2100
7	2000	3000
8	1200	2900
9	1000	1600
10	1300	1500
11	1100	1300
AVERAGE	1675	2191

*Four years experience as Intelligence Targeting Officer for NUC/CONV weapons, F-4D aircraft.

TABLE D-2

Accumulated Values Determined Using MADCAMP Scoring Function by Source and Test Mission

TEST MISSION	1	2	3	4	5	MADCAMP
1	2029	1824	1844	1814	1563	1667
2	1102	959	1722	1361	1809	952
3	631	800	1774	1675	991	615
4	2301	1870	1989	1828	2245	1564
5	2284	1898	1455	1740	1772	1150

TABLE D-3

Flight Path Source Rankings by Test Mission

TEST MISSION	EFFECT	SOURCE OF FLIGHT PATH 1	2	3	4	5	MADCAMP
1	Rankers	5	2	4	1	3	6
	MADCAMP	6	4	5	3	1	2
2	Rankers	5	3	2	1	6	4
	MADCAMP	3	2	5	4	6	1
3	Rankers	1	3	4	5	6	2
	MADCAMP	2	3	6	5	4	1
4	Rankers	3	2	4	5	6	1
	MADCAMP	6	3	4	2	5	1
5	Rankers	6	3	5	2	4	1
	MADCAMP	6	5	2	3	4	1

VITA

Robert H. Whitney was born on 25 November 1944 in Arco, Idaho. He graduated from high school in Mackay, Idaho in 1963 and attended Idaho State University from which he received the degree of Bachelor of Science in Mathematics in February 1968. Upon graduation, he was employed by the Idaho Nuclear Corporation, Idaho Falls, Idaho as a Reactor Engineer on the Experimental Test Reactor (ETR). In July 1969 he entered the USAF and received a commission through the OTS program. He completed navigator training in August 1970 and served one year as a C-141 navigator with the 20th MAS Dover AFB, De. In October 1971 he cross-trained to the F-4 tactical fighter where he served as a Weapon Systems Officer (WSO) with the 58 TFS Eglin AFB, Fla, as a IWSO and Wing Emergency Actions Officer with the 494 TFS and the 48 TFW RAF Lakenheath, U.K., and as RWR/ECM Academic Instructor, 35 TTS; ISWO, 561 TFS; and Wing Stan/Eval Flight Examiner 35 TTW George AFB, Ca. He entered the School of Engineering, Air Force Institute of Technology, in August 1979.

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VITA

Jack L. Wilson was born on August 1946 ih Salem, Oregon. He graduated from high school in Salem, Oregon in 1964 and attended Oregon State University from which he received a Bachelor of Science degree in Mechanical Engineering in June 1968. Upon graduation, he received a regular commission in the USAF through the ROTC program. He completed pilot training and received his wings in June 1969. He then served as an undergraduate T-38 instructor pilot at Williams AFB, Arizona. Following a one year remote tour as chief of Airfield Management at King Salmon AFS, Alaska, he was assigned to Edwards AFB, Ca, as a flight test engineer. While stationed at Edwards AFB, he received a Masters of Science degree in Systems Management from the University of Southern California. He was then assigned to Kirtland AFB, New Mexico, as a Flight Operations Officer for the Air Force Contract Management Division, AFSC, where he remained until entering the School of Engineering, Air Force Institute of Technology, in September 1979.

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